Nuclear Power

THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

Plug

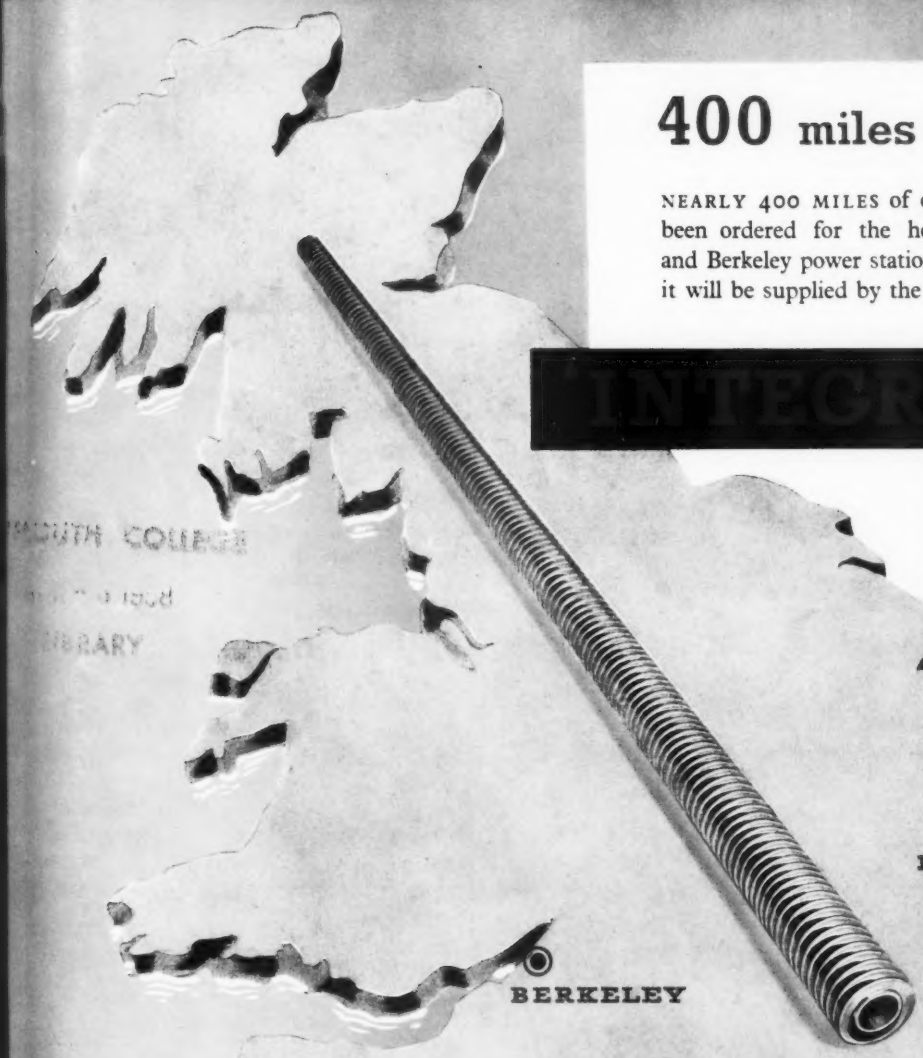
400 miles of 'Integron'

NEARLY 400 MILES of extended surface tubing has been ordered for the heat exchangers of Bradwell and Berkeley power stations. And every single foot of it will be supplied by the Metals Division of I.C.I.

INTEGRON

INTEGRAL-FINNED TUBING

This is only one of the many important contributions made by I.C.I. Metals Division to the development of nuclear engineering



BRADWELL

BERKELEY

First in Nuclear Metals

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.I.

ICI METALS DIVISION

A ROWSE MUIR PUBLICATION

APRIL 1958 3/6

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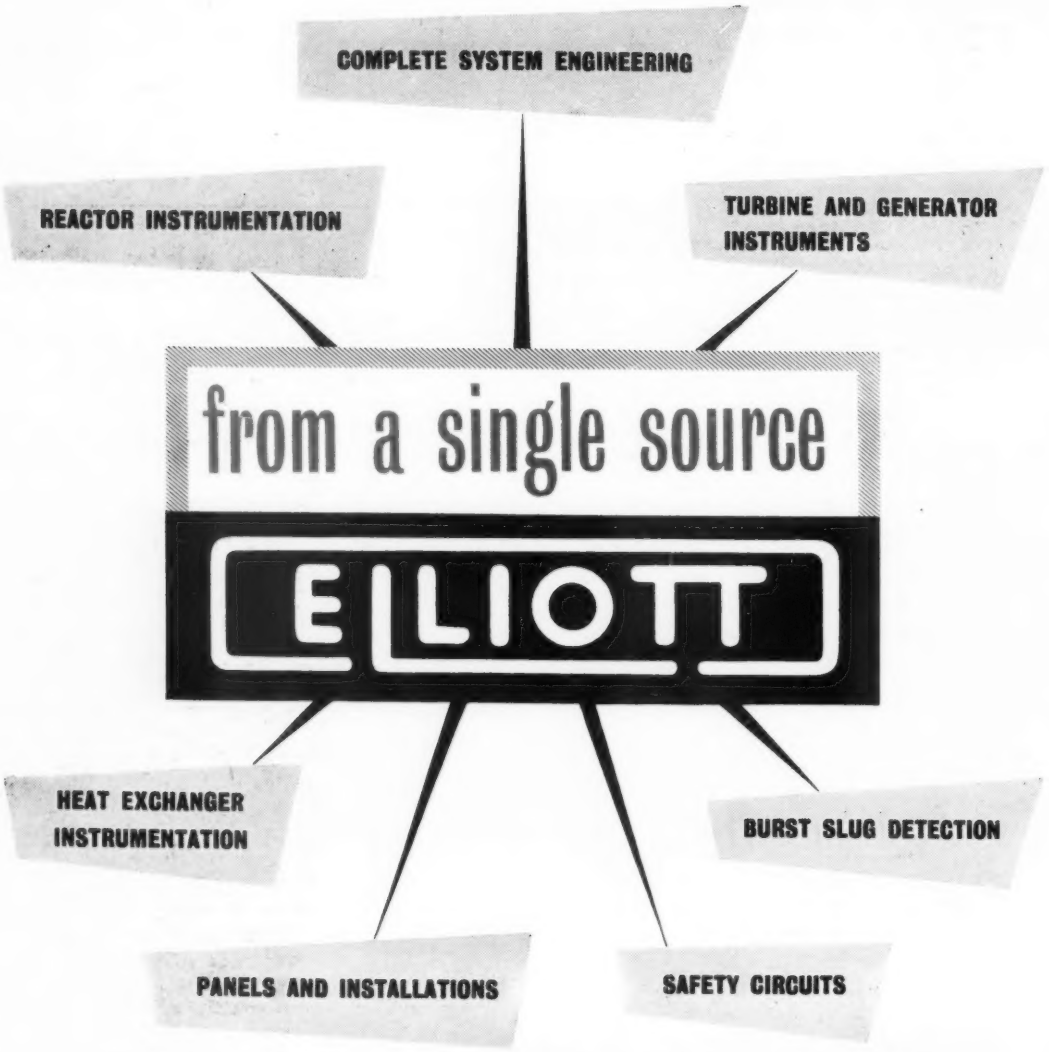

COMPLETE INSTRUMENTATION FOR NUCLEAR POWER STATIONS

Elliott Brothers (London) Ltd. have supplied instrumentation to Calder Hall 'A' and 'B' Power Stations and to the research reactors of the U.K.A.E.A. In addition to the Company's contribution to the C.E.A.'s programme, it has been entrusted with the development of control and safety systems for Britain's first nuclear submarine, H.M.S. Dreadnought, and has supplied and installed all the instrumentation for the Zero Energy Experiment.

ELLIOTT BROTHERS (LONDON) LIMITED, CENTURY WORKS, LEWISHAM, LONDON, S.E.13 • TELEPHONE: TIDEWAY 1271

A MEMBER OF THE ELLIOTT-AUTOMATION GROUP.

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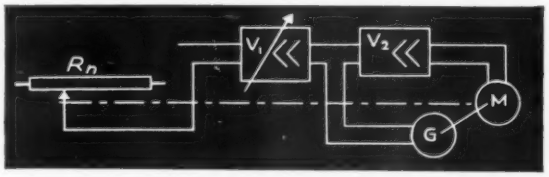
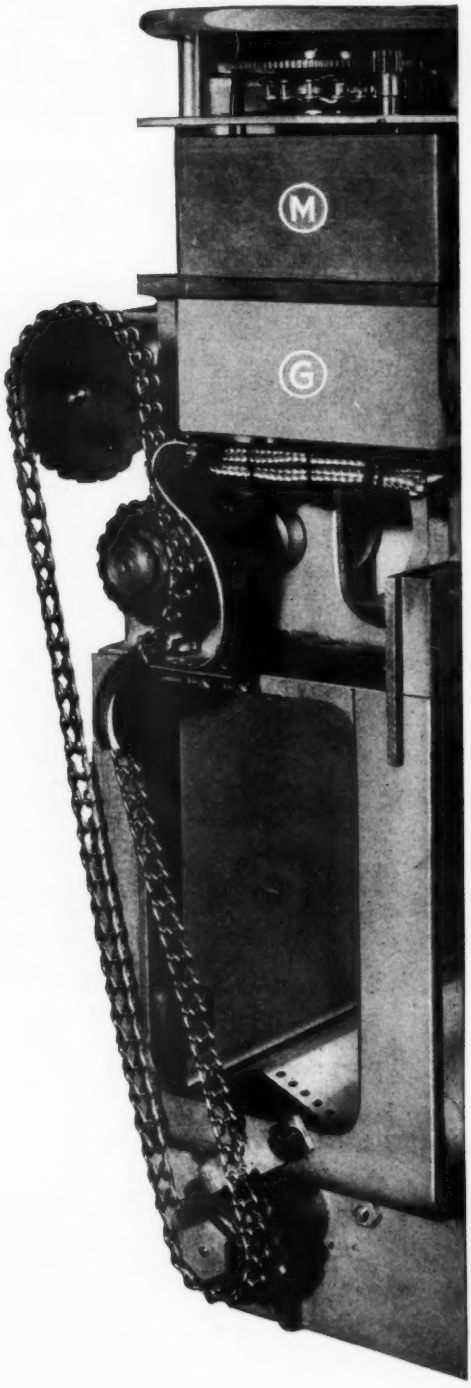
The principle of the damping system:

M = *Servo-motor: two-phase induction type. Two stator windings energised from mains, two (with 90° phase-shift) from output stage of push-pull amplifier. Direction of rotation phase-dependent on amplifier input signal.*

G = *Tacho-generator, mechanically coupled. Delivers voltage linearly proportional to speed of slide-wire contact.*

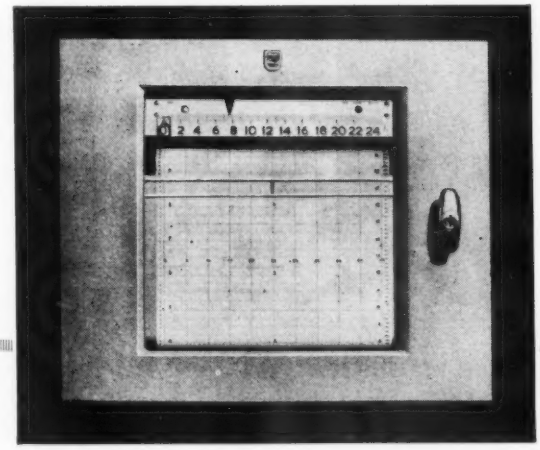
V1: V2 = *Amplifier. First stage (V1) adjustable. Voltage generated by G fed back into V2. Output from amplifier applied to servo exerts braking action on rotor.*





No overshoot with this potentiometric recorder by **PHILIPS**

In an instrument with a fast response time, accuracy demands that the measures taken to arrest momentum must be more than usually effective and always critically sensitive. Over a full scale-length of 25 cm., most versions of potentiometric recorders by Philips have a balancing time of only *one second* and a positioning accuracy of 0.1% of the total measuring range.
For the measurement and control of practically any variable reproducible as an electrical signal, there is a Philips potentiometric recorder to match the need.
We welcome your enquiries.



PHILIPS

PHILIPS ELECTRICAL LTD

RESEARCH AND CONTROL INSTRUMENTS DIVISION
Century House · Shaftesbury Avenue · London · W.C.2
Telephone : GERrard 7777

(PRCO265)

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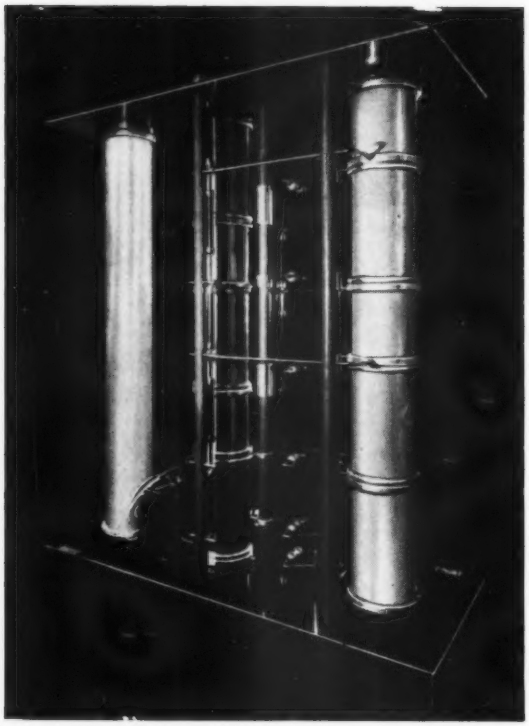
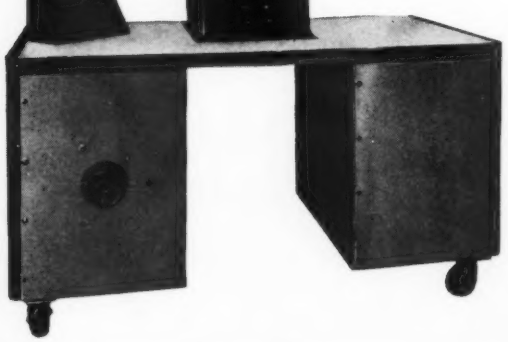
high voltage ENGINEERING



Impulse Generator

A new range of Impulse Generating equipment has been designed for voltages between 100 and 750 kv.
It is complete with single sweep oscilloscope and measuring sphere gaps.
All Generators are built to customer's specification. The smaller models are built in London and shipped complete. The larger models are built on site by our own staff.

A 350 kv. Generator complete with capacity divider — the ball gaps are remotely controlled from the desk.



The control desk, with charging unit incorporated, complete with single sweep oscilloscope and camera.

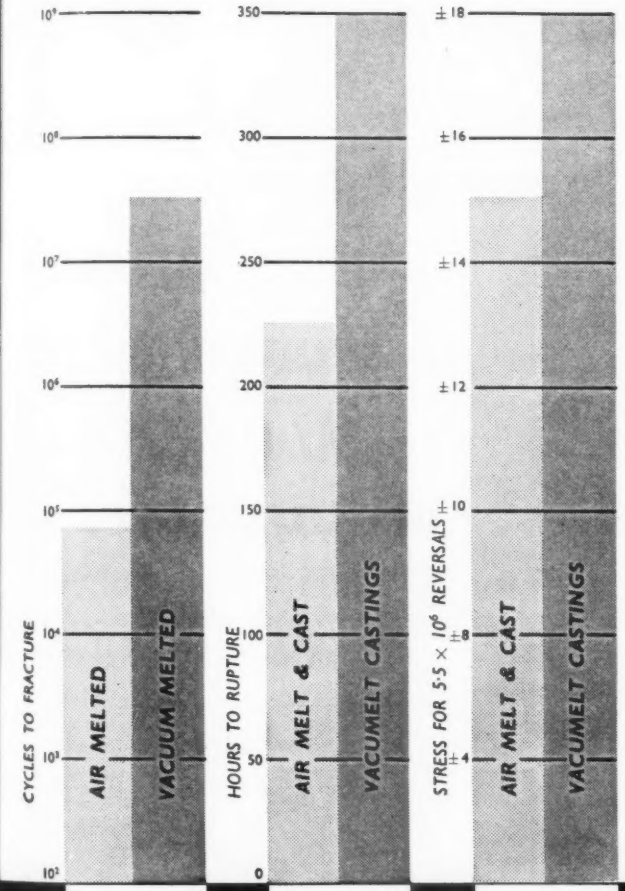
HIVOLT LTD

LONDON 91-93 PRINCEDALE ROAD, W.11. Phones:- PARK 5073/5
MANCHESTER TENAX ROAD, TRAFFORD PARK TRAFFORD 0700

SPECIALIST MANUFACTURERS OF HIGH VOLTAGE GENERATING, INSULATION & MEASURING EQUIPMENT

VACUMELT

VACUUM MELTED STEELS



FATIGUE STRENGTH OF CARBON CHROMIUM BALL RACE STEEL

CREEP RUPTURE LIFE OF CAST G34 (COBALT BASE ALLOY) TESTED AT 17·0 TONS/SQ. IN. AT 750°C

FATIGUE STRENGTH OF CAST G34 (COBALT BASE ALLOY)

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a great step forward in steel

Once again Jessops make a contribution to metallurgical technology of first importance, in producing on a commercial scale *steels melted in Vacuum.*

Vacumelt Steels have these outstanding features

GREATER PURITY
Freedom from impurities means greater safety in highly stressed components.

IMPROVED DUCTILITY
Particularly in directions at 90° to grain flow.

GREATER STRENGTH
Comparative tests against air melted steels have shown Vacumelt steels to have in most cases superior tensile, creep and fatigue qualities. Actual test results are shown.

AVAILABILITY
Vacumelt steels are readily available in most qualities. Ingots up to 2 tons can be produced and also blooms, billets, bars, forgings, sheet and strip. Among the many applications demanding the freedom from impurities offered by Vacumelt steels the following are obvious:—ball races and bearings, compressor blades and discs, turbine blades and discs, high grade polished sheet, certain high finish tools and dies, fine gauge steel wire.

WILLIAM JESSOP & SONS LTD BRIGHTSIDE WORKS SHEFFIELD

ONE OF THE B.S.A. GROUP OF COMPANIES

Jessop have the name for TITANIUM

It's ***Hylite*** **Details on request**

Write for full technical data

P

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recent contracts include

AIR HEATING STEAM CONDITIONING SERVICES

POWER STATIONS

PRINTING WORKS

CAR FACTORIES

DEPARTMENTAL STORES

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AERODROMES

BY APPOINTMENT TO
HER MAJESTY
QUEEN ELIZABETH II
HEATING ENGINEERS
& STOKER MAKERS

ASHWELL & NESBIT LTD.

HEAD OFFICE: BARKBY ROAD, LEICESTER
LONDON: 12 GREAT JAMES STREET, W.C.1
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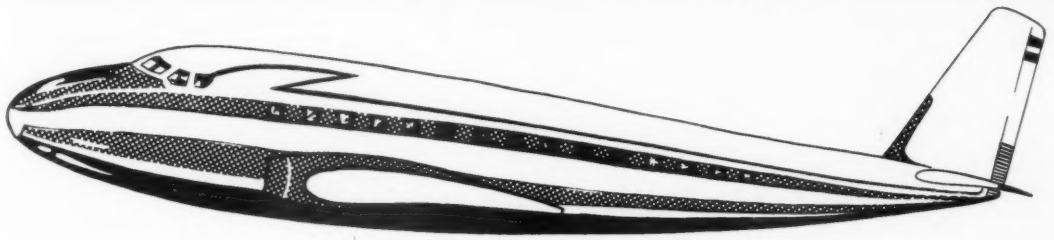
MANCHESTER (13): 184 OXFORD ROAD
LEEDS (6): 32 HEADINGLEY LANE
GLASGOW: 15 FITZROY PLACE, C.3
BELFAST: 14 CORPORATION STREET

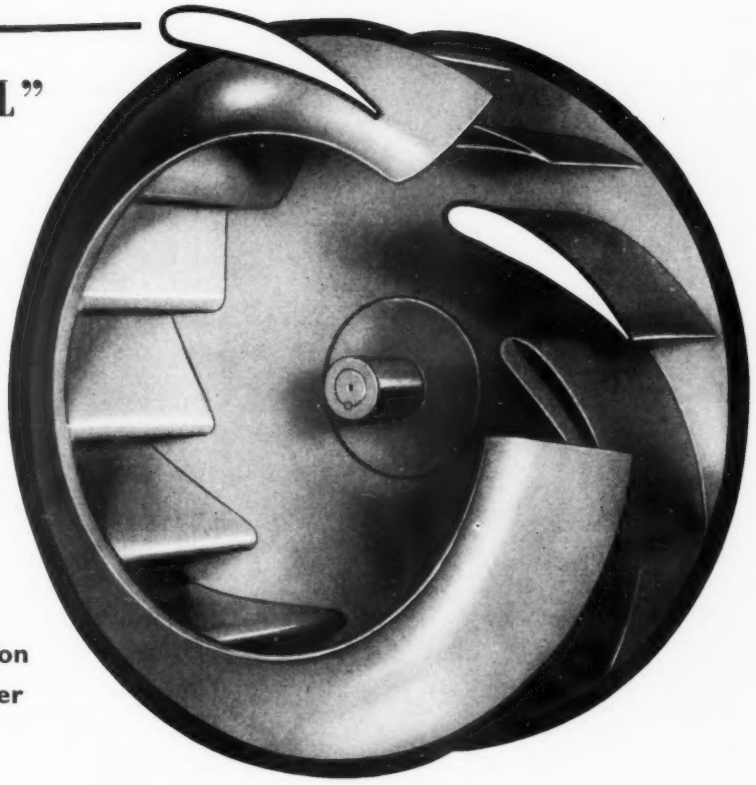
A NATION WIDE ORGANIZATION TO DEAL WITH ANY TYPE & SIZE OF CONTRACT

A4

NOTE THE AERODYNAMIC DESIGN



"GYRA-FLO AIRFOIL" IMPELLER BLADES, BLADE SHROUDS and INLET CONES



. . . . combine to provide "Gyra-Flo Airfoil" Fans with efficiencies of over 90%. Efficiencies of over 70% are maintained over 55% of the operating range and a reduction of 25% in absorbed horse-power is effected.

GYRA-FLO TRADE MARK
AIRFOIL CENTRIFUGAL FANS

Our Engineers will be pleased to advise.

THE MIDLAND HEATING & VENTILATION CO. LTD.

BIRMINGHAM :- VICtoria 3781 . GLASGOW :- BIShopbriggs 2667 . STOCKPORT :- WOOdley 3611

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Micro Switchcraft by

BURGESS

THE BRITISH MICRO SWITCH DESIGN
AND MANUFACTURING SPECIALISTS

BURGESS PRODUCTS CO. LTD., MICRO SWITCH DIVISION, DUKES WAY, TEAM VALLEY, GATESHEAD 11. Tel: Low Fell 75322. Telex: 53-229

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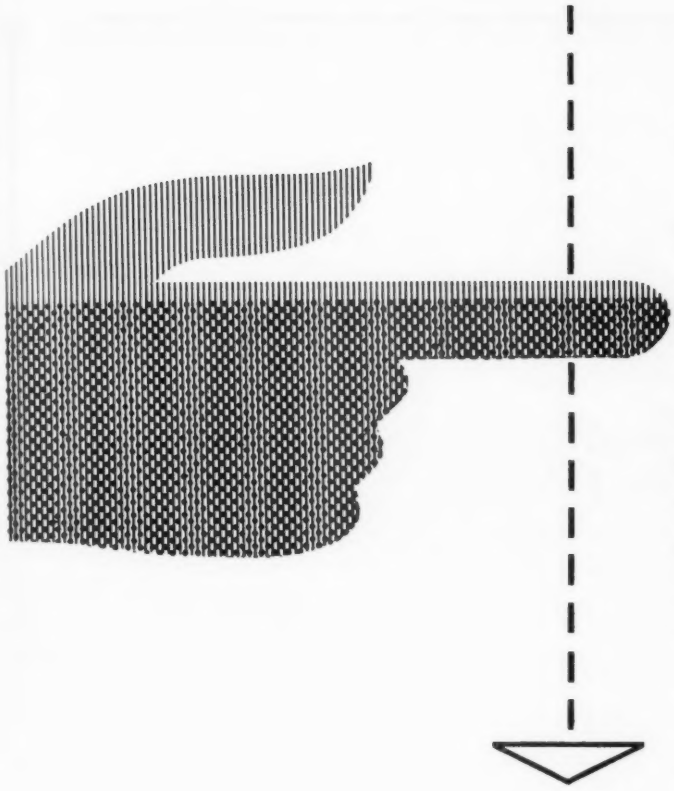

Burst slug display

As the size of gas-cooled reactors increases, use of computer technique for burst slug detection and display, in place of the earlier recorder methods, becomes essential. The many advantages of a computer technique are illustrated by equipment now being made by Sunvic Controls.

- ★ Compact display with flexible programming facilities allows presentation of only that information required for immediate assessment of abnormal activity.
- ★ Individual channel group reference levels and differential limits: magnetic memory drum for previous 24 hours readings; facilities for averaging past values.
- ★ All results calculated to three significant figures —no calibration errors.
- ★ Completely self-checking circuitry with built-in fault-finding facilities.

The burst slug detection display system described above (for which patents are pending), was wholly developed by Sunvic engineers, who are available to discuss its application to any power reactor. Please contact:

SUNVIC CONTROLS LTD
P.O. BOX 1 · HARLOW · ESSEX.
Tel: Harlow 25271

An artist's impression of the gas activity monitoring display equipment being built for C.E.G.B. use at the Berkeley nuclear power station by Sunvic, who are also supplying instrumentation for the boilers and blowers.

SUNVIC
An A.E.I. Company

Not only instruments but complete instrumentation
for integrated monitoring, control and data handling of nuclear reactors and industrial processes.

SC 66

Tudor

are pleased to announce that they have

been awarded contracts for supplying

batteries and associated equipment for

HUNTERSTON

(Sub-Contract from the General Electric Co. Ltd.)

BRADWELL

(Sub-Contracts from The Nuclear Power Plant Co. Ltd., and A. Reyrolle & Co. Ltd.)

Tudor have also supplied batteries and associated equipment to the following nuclear power stations:

CALDER HALL 'A'
CALDER HALL 'B'
CHAPEL CROSS
DOUNREAY

(Supplied under sub-contracts from:
A. Reyrolle & Co. Ltd.
The English Electric Co. Ltd.
Brush Electrical Engineering Co. Ltd.)

Tudor

Specialists in battery work for nuclear power stations

THE TUDOR ACCUMULATOR COMPANY LTD., 137 VICTORIA STREET, LONDON SW1 TEL: TATe Gallery 0307

WORKS: DUKINFIELD, CHESHIRE TEL: ASHTON-UNDER-LYNE 1651

T.170

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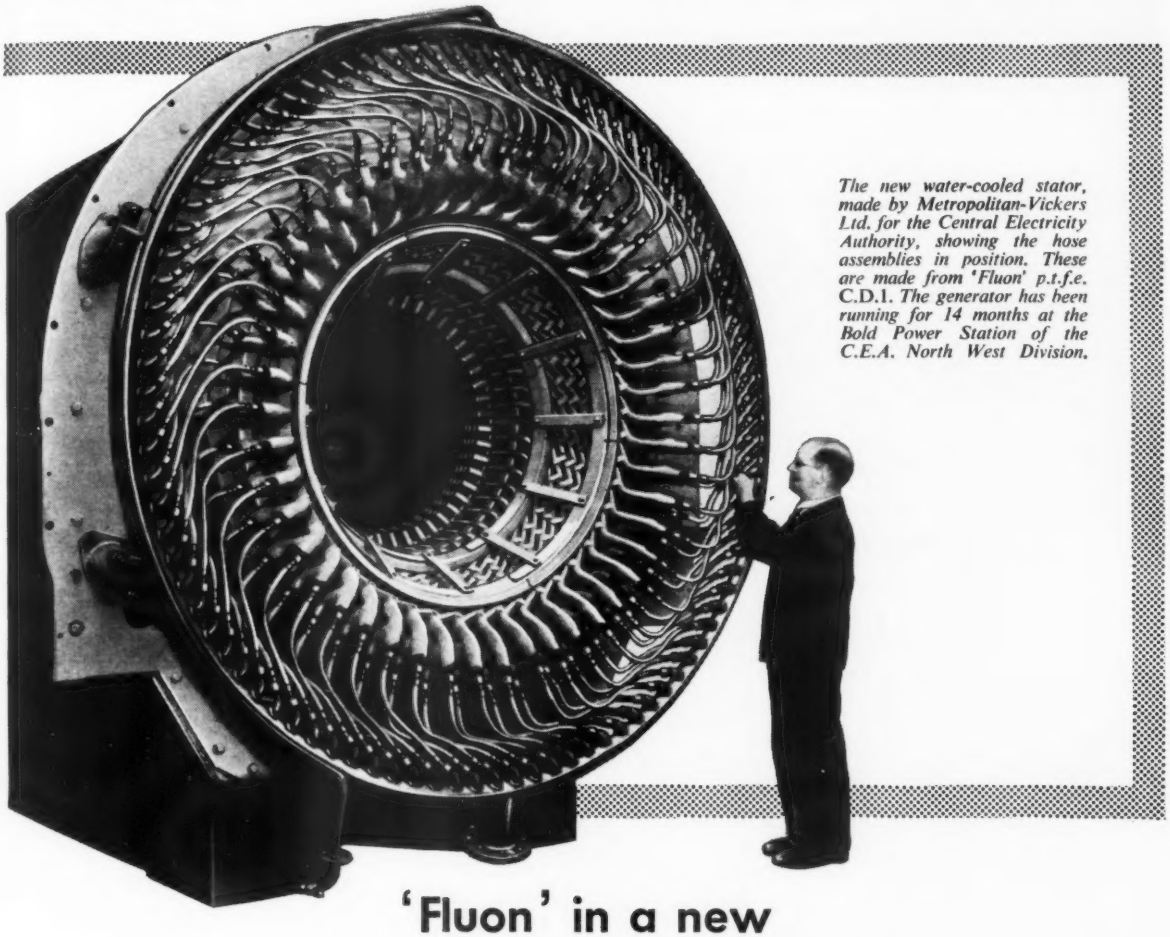
'FLUON' *increases production in the Electrical Industry. No.1*



The new water-cooled stator, made by Metropolitan-Vickers Ltd. for the Central Electricity Authority, showing the hose assemblies in position. These are made from 'Fluon' p.t.f.e. C.D.1. *The generator has been running for 14 months at the Bold Power Station of the C.E.A. North West Division.*

'Fluon' in a new water-cooled turbo-generator

A MAJOR PROBLEM in the design of large generators is the cooling system. With the introduction of hollow conductors it became clear that water would be the best cooling agent if only the problems of feeding the water to and from the conductors could be overcome. 'Fluon' is playing a key part in solving these problems.

In this new water-cooled generator the flow of water is from one end to the other through all the conductors in parallel, passing through insulating hoses to each conductor while similar hoses at the other end carry the water to the outlet manifold.

These hoses must have a service life comparable with other components used in the construction of electrical machines. They must, therefore, withstand shock and vibration, operate at elevated temperatures and resist corrosion and degradation due to ageing for an indefinite period. A wide range of hose materials, including metals, rubbers and plastics, was examined and all with the exception of the coagulated dispersion polymer of tetrafluoroethylene ('Fluon' C.D.1) failed to meet these requirements.

'Fluon' C.D.1 possesses all the remarkable properties of p.t.f.e. and in addition extruded tubes have a service life far beyond the range of traditional hose materials.

'Fluon' C.D.1 has been developed not only as a material for the extrusion of thin wall tubes and insulating sleeves but also for sheathing electric wires and cables. In particular it is an ideal insulator for equipment wires.

'FLUON'

'Fluon' is the registered trade mark for the polytetrafluoroethylene manufactured by I.C.I.

ICI

PF.36

IMPERIAL CHEMICAL INDUSTRIES LIMITED · LONDON · S.W.1.

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A machine shop specially established for machining graphite under "Clean Conditions" is now in operation at our Hayes Works. This new department supplements our already extensive facilities for machining commercial graphite and is fully equipped with specialised plant for high precision work. It is capable of producing all types of graphite components for nuclear purposes.

GRAPHITE MACHINING

These photographs show the graphite for the NATURAL URANIUM GRAPHITE MODERATED EXPONENTIAL EXPERIMENT at Imperial College, London being machined in the new department. Further facilities for precision machining of full production quantities under "Clean Conditions" are now being installed.

Powell Duffryn

CARBON PRODUCTS LIMITED

DELANIUM
CARBON & GRAPHITE

SPRINGFIELD ROAD, HAYES, MIDDLESEX
TELEPHONE: HAYES 3994

OUR VALVES HAVE MANY FACES

Did you know that each one of our automatic control valves has a personality of its own? Take 'Safety Cut-out', for instance. Now, he's a careful type who shuts up like a clam whenever his electrical circuit is disturbed and flatly refuses to allow either liquids or gases to pass. Or there's 'Balanced 3-way'. This fellow is a leader and controls other chaps doing all the hard work — Pneumatic and Hydraulic cylinders for example. We have over 100 different 'types' of valves for every kind of automatic or remote control system involving water, steam, coal gas, oil, air and many other industrial liquids and gases. They don't use glands, stuffing-boxes or driving shafts and, what's more, they have a reputation for hard work, long life and the utmost reliability. Full technical details of this family of automatic control valves are contained in our new brochure No. 402. Why not write *NOW* for your copy?

Well over 100 of them, in fact. A 'type' to suit every requirement.

MAGNETIC VALVES ARE USED EXTENSIVELY IN

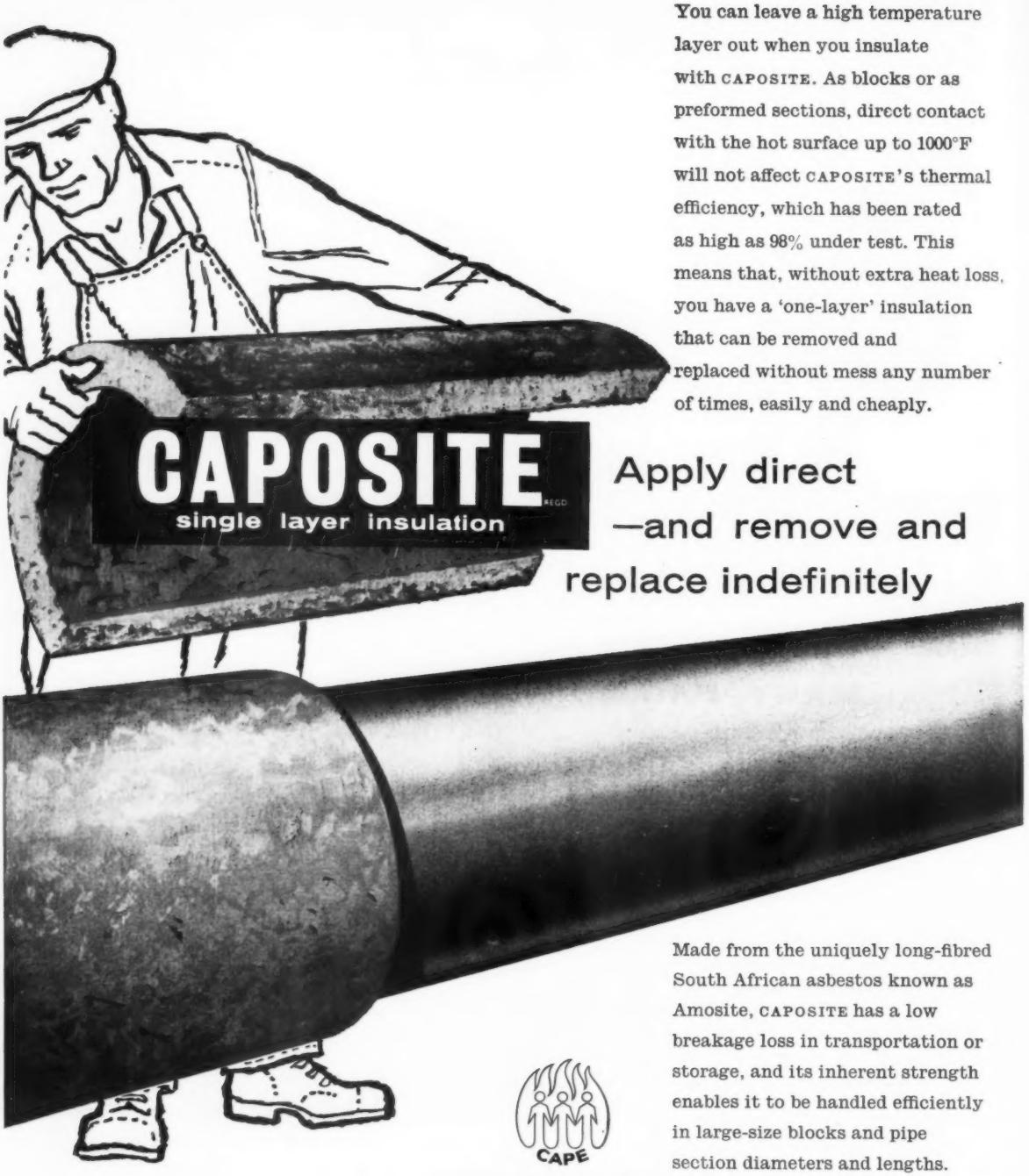
AIR CONDITIONING	LAUNDRY PLANT
AUTOMATIC STOKERS	MACHINE TOOLS
BOILERS	OIL BURNERS
CENTRAL HEATING	REFRIGERATION
CRUCIBLE BAKING OVENS	NUCLEAR POWER PLANT
DYEING	STERILISING PLANT
GAS GENERATING PLANT	STEAM TURBINES
HYDRAULIC & PNEUMATIC	TINNING BATHS
CYLINDER MECHANISMS	VACUUM PUMPS
HOT WATER SERVICES	VENTILATION

MVC

The Magnetic Valve Company Ltd

28 ST. JAMES'S PLACE, LONDON S.W.1 · TELEPHONE HYDE PARK 7588

MV2



You can leave a high temperature layer out when you insulate with CAPOSITE. As blocks or as preformed sections, direct contact with the hot surface up to 1000°F will not affect CAPOSITE's thermal efficiency, which has been rated as high as 98% under test. This means that, without extra heat loss, you have a 'one-layer' insulation that can be removed and replaced without mess any number of times, easily and cheaply.

CAPOSITE
REGD
single layer insulation

Apply direct —and remove and replace indefinitely

Made from the uniquely long-fibred South African asbestos known as Amosite, CAPOSITE has a low breakage loss in transportation or storage, and its inherent strength enables it to be handled efficiently in large-size blocks and pipe section diameters and lengths.

CAPE

CAPOSITE
REGD

Amosite Asbestos Blocks and Pipe Sections

Write for full technical details to:
THE CAPE ASBESTOS COMPANY LTD. 114 & 116 Park Street, London, W.1. Tel: GROsvenor 6022
and at GLASGOW: Eagle Buildings, 217 Bothwell Street, Glasgow C2. Tel: CENtral 2175
MANCHESTER: Floor D, National Buildings, St. Mary's Parsonage, Manchester 3. Tel: Deansgate 6016-7-8
BIRMINGHAM: 11 Waterloo Street, Birmingham 2. Tel: Midland 6565-6-7
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TA 295

RAWLPLUG

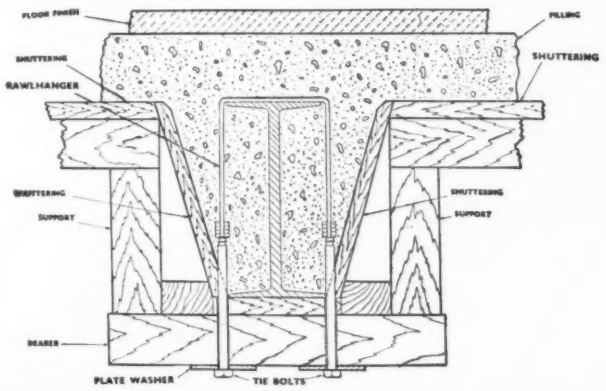
FIXING DEVICES FOR CONSTRUCTIONAL WORK IN CONCRETE

RAWLHANGERS

Rawlhangers, as illustrated, used in place of struts, offer two very important advantages. Not only do they, by eliminating strutting, provide a clear working space free of all obstruction, but they leave embedded in the ceiling tapped nuts, to which can be attached hangers for carrying Pipe Work, Shafting, Ventilator Ducts, Cable Racks, etc. A further point is that if desired, any particular one or all floors can be worked on at the same time.

Rawlhangers, together with Rawloops and Rawlties are designed to facilitate the speedy erection, dismantling and re-erection of formwork for all types of concrete work. This is achieved by providing anchorages to which the shuttering can be fixed and from which it can be removed in a matter of minutes.

CLADDING R.S.J.'s USING RAWLHANGERS, WOODEN SHUTTERING, BEARERS, ETC.



SOME OF THE ADVANTAGES OF THE RAWLHANGER METHOD

1. **Easy and rapid assembly and striking of formwork; hence great saving in labour costs.**
2. **Perfect alignment.**
3. **Effective stoppering.**
4. **Adaptable to all forms and types of construction.**
5. **Saves material, struts not required.**
6. **Bolts re-usable.**

For further information write to Technical Service Department.

THE RAWLPLUG COMPANY LTD., LONDON, S.W.7

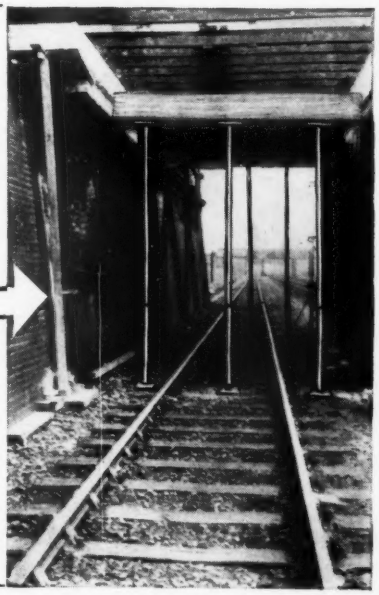
THE OLD METHOD

Where props are used to support the shuttering, the freeway is completely blocked thus stopping the flow of traffic.

THE RAWLHANGER METHOD

Props eliminated, thus allowing free flow of work and traffic below concreting operations.

B570



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HEAT

SPEEDS PRODUCTION

The application of heat at a certain point will increase the efficiency of — and speed up — many industrial processes. A way of proved efficiency to apply heat — and sometimes the only practical way — is by means of *HOT AIR*. This can be done by using a centrifugal fan to blow air through a specially designed heating chamber and directing the hot air to the required spot.

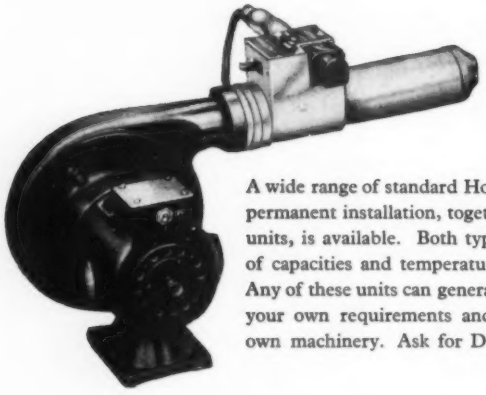
Secomak REG.

Re-entrant Heater

This new addition to the Secomak range has been designed to produce exceptionally high temperatures with lower loadings. Temperatures 25% higher than those from standard heaters are now obtainable with similar loadings — or equivalent temperatures with loadings 25% to 30% lower.

Higher temperatures at lower loadings !

up to 900° F.



. . . just one of the answers to production lags provided by the Secomak REG.

A wide range of standard Hot Air Blowers for permanent installation, together with portable units, is available. Both types cover a range of capacities and temperature up to 900° F. Any of these units can generally be adapted to your own requirements and built into your own machinery. Ask for Data Sheet 130/53.

range of industrial blowing and suction equipment

The range also includes sound signalling appliances for marine and industrial use

SERVICE ELECTRIC CO. LTD. HONEYPOT LANE, STANMORE, MIDDLESEX.

Manufacturing Electrical and Mechanical Engineers. Contractors to Admiralty and Ministry of Supply. A.I.D. approved. *EDSware 5566/9.*

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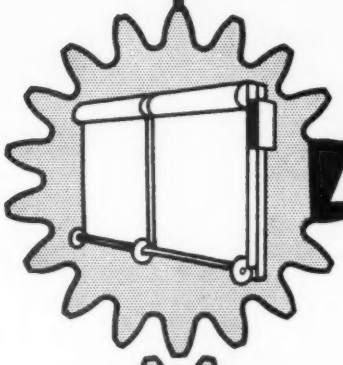
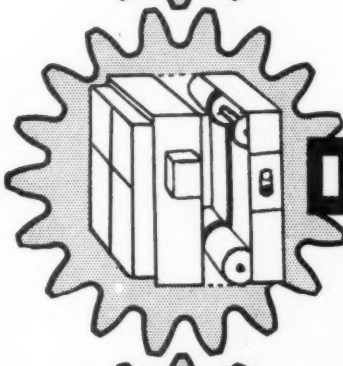
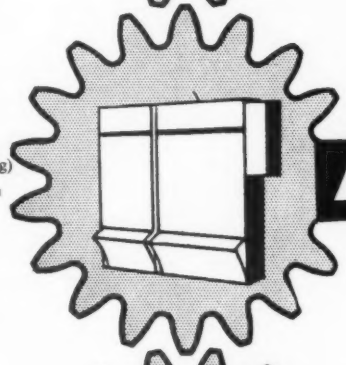


AUTOMATION



IN

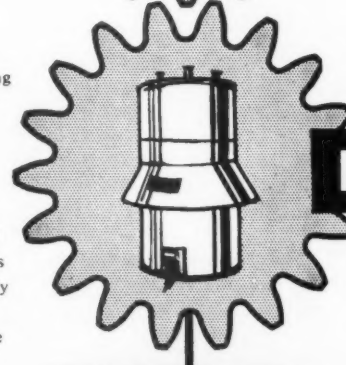
ROLL-O-MATIC
(Patents Pending)
A self-maintaining filter with a renewable curtain of bonded glass fibre. More Roll-O-Matic filters are in service than any other make of filter of this type.



AIR

ROLLOTRON
(World Patents Pending)
A unique combination of high efficiency electrostatic precipitation and automatic renewing media.

MULTI-DUTY
An original design of positive self-cleaning viscous impingement filter.



FILTRATION

CYCOIL
A compact filter combining centrifugal separation and viscous impingement; specially developed for air compressors and large diesel engines.

Filter maintenance is a thing of the past with our range of self-maintaining filters. Once installed, they work automatically and need little more than routine inspection at infrequent intervals. May we send you full details?

AIR CONTROL
INSTALLATIONS LIMITED

RUISLIP · MIDDLESEX · RUISLIP 4066

LONDON · BIRMINGHAM · MANCHESTER · NEWCASTLE · GLASGOW

Air Control Installations Ltd are the sole manufacturing licensees in Great Britain for products of the American Air Filter Co., Inc.

NS · FILTERS · DUST COLLECTORS · AIR CONDITIONERS · FANS · FILTERS · DUST COLLECTORS · AIR CONDITIONERS · FANS · FILTERS · DUST

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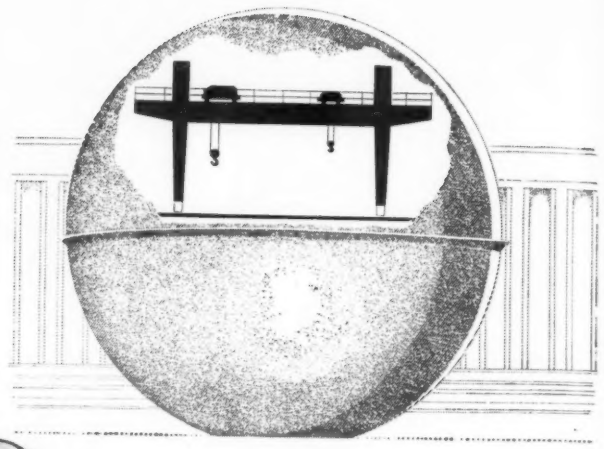

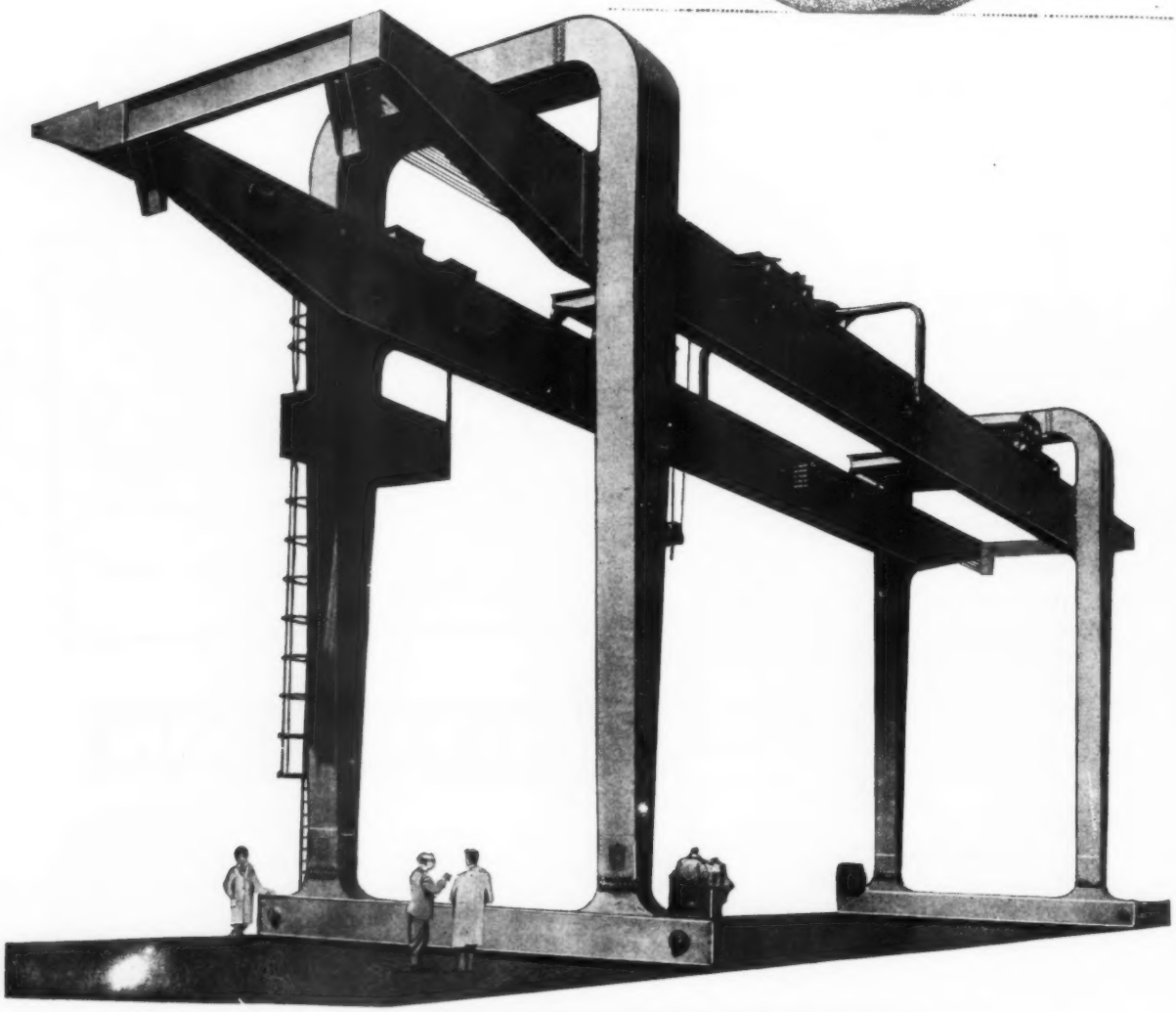

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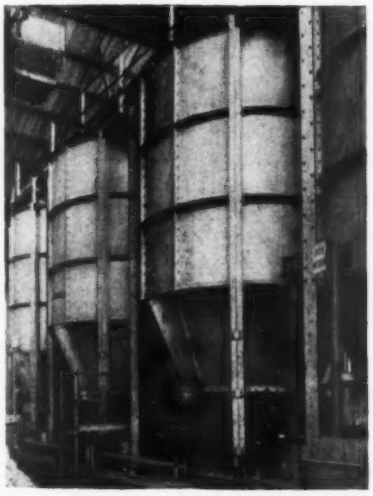

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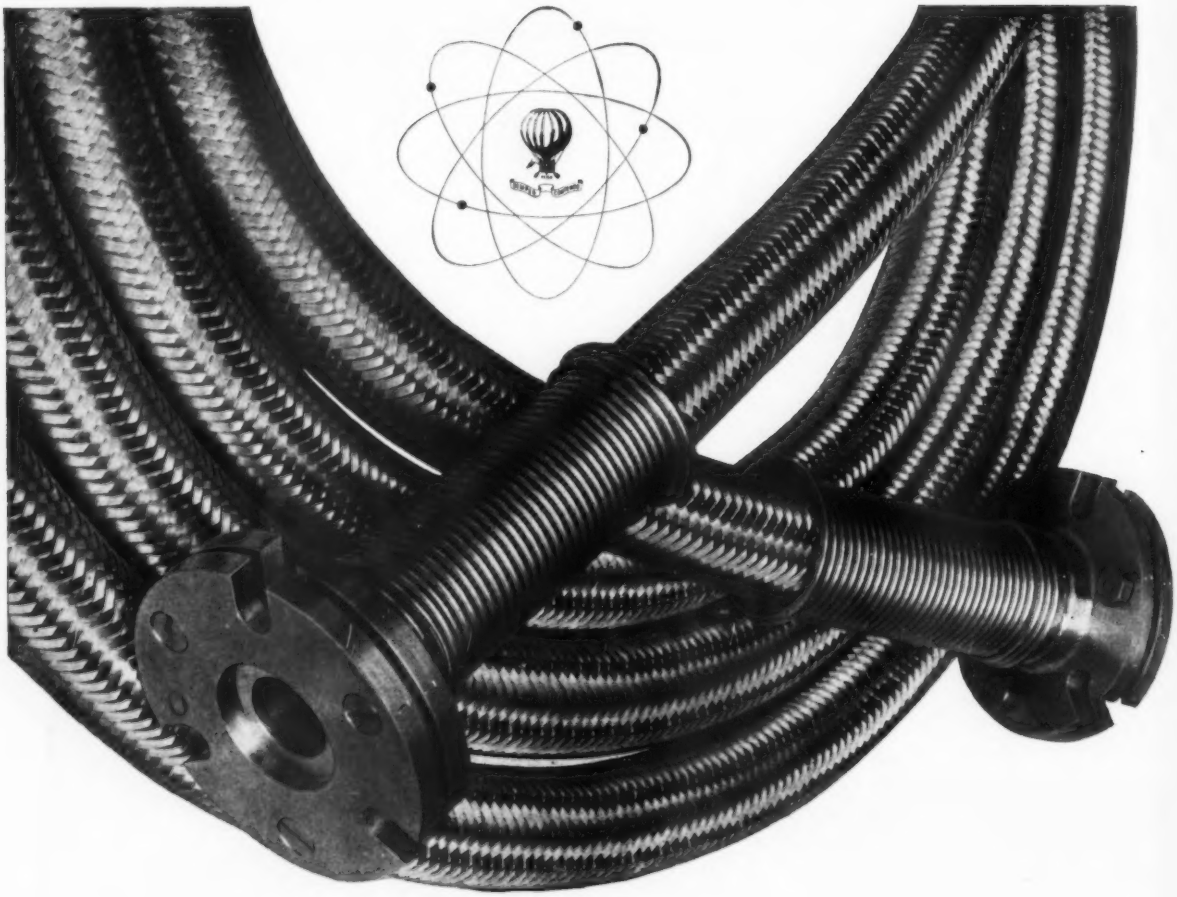

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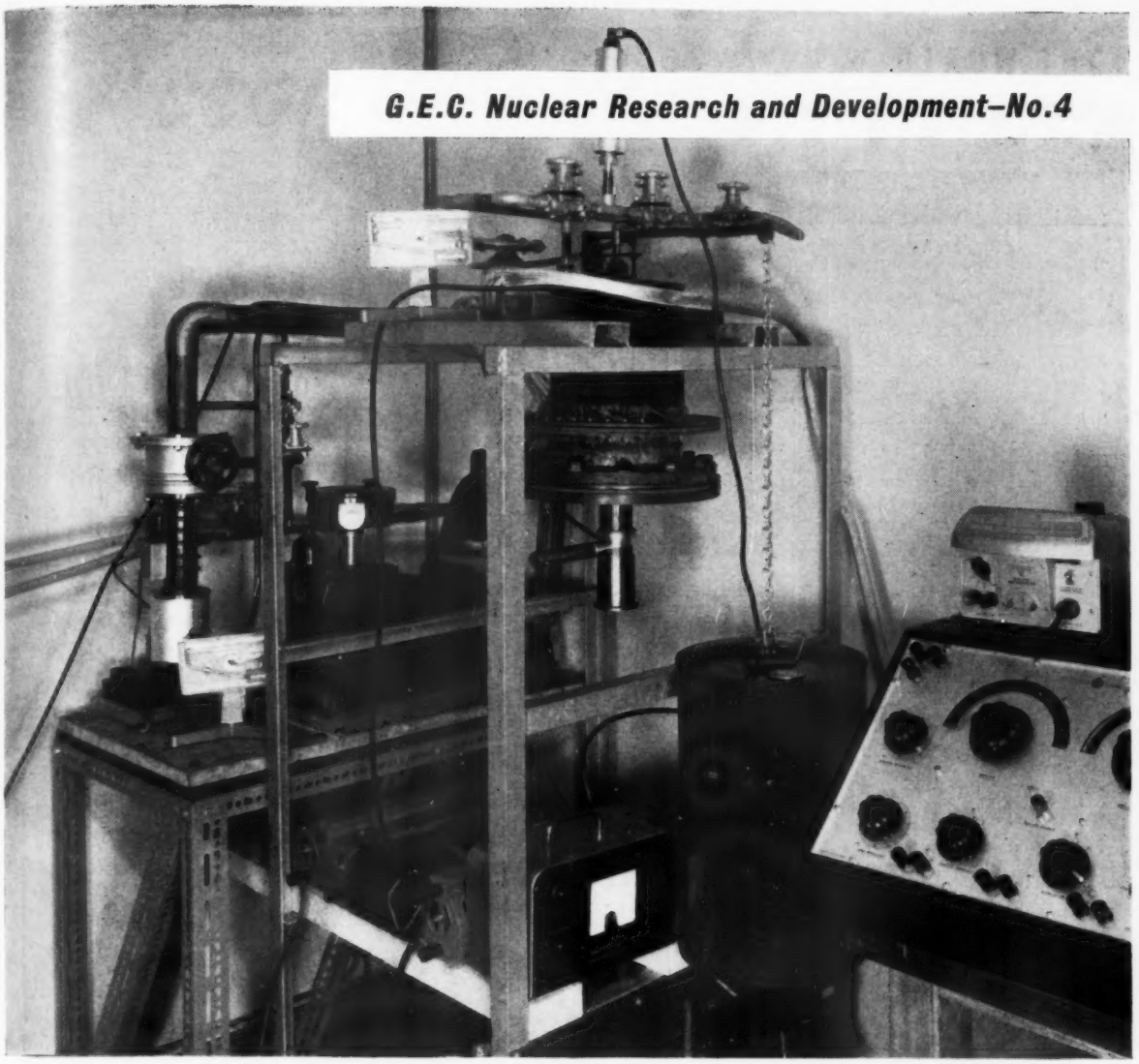

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In a nuclear power reactor metallurgical considerations impose a limit on the temperatures that can be allowed in the uranium fuel rods. At the same time it is essential, for efficient heat transfer to the gas, that the can should be as hot as possible. It is thus necessary to determine the temperature drop that will occur between the centre and the surface of a fuel element.

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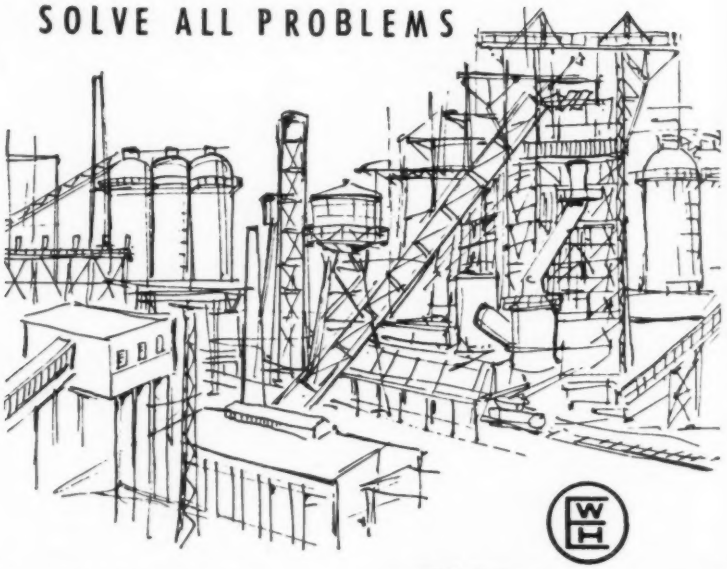

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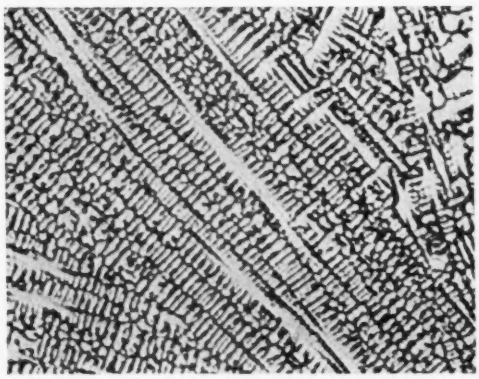

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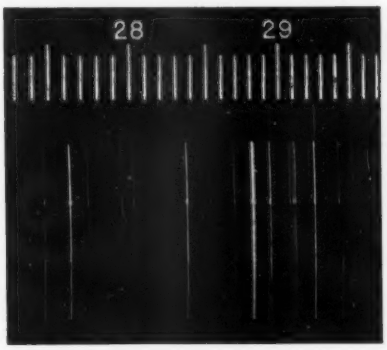

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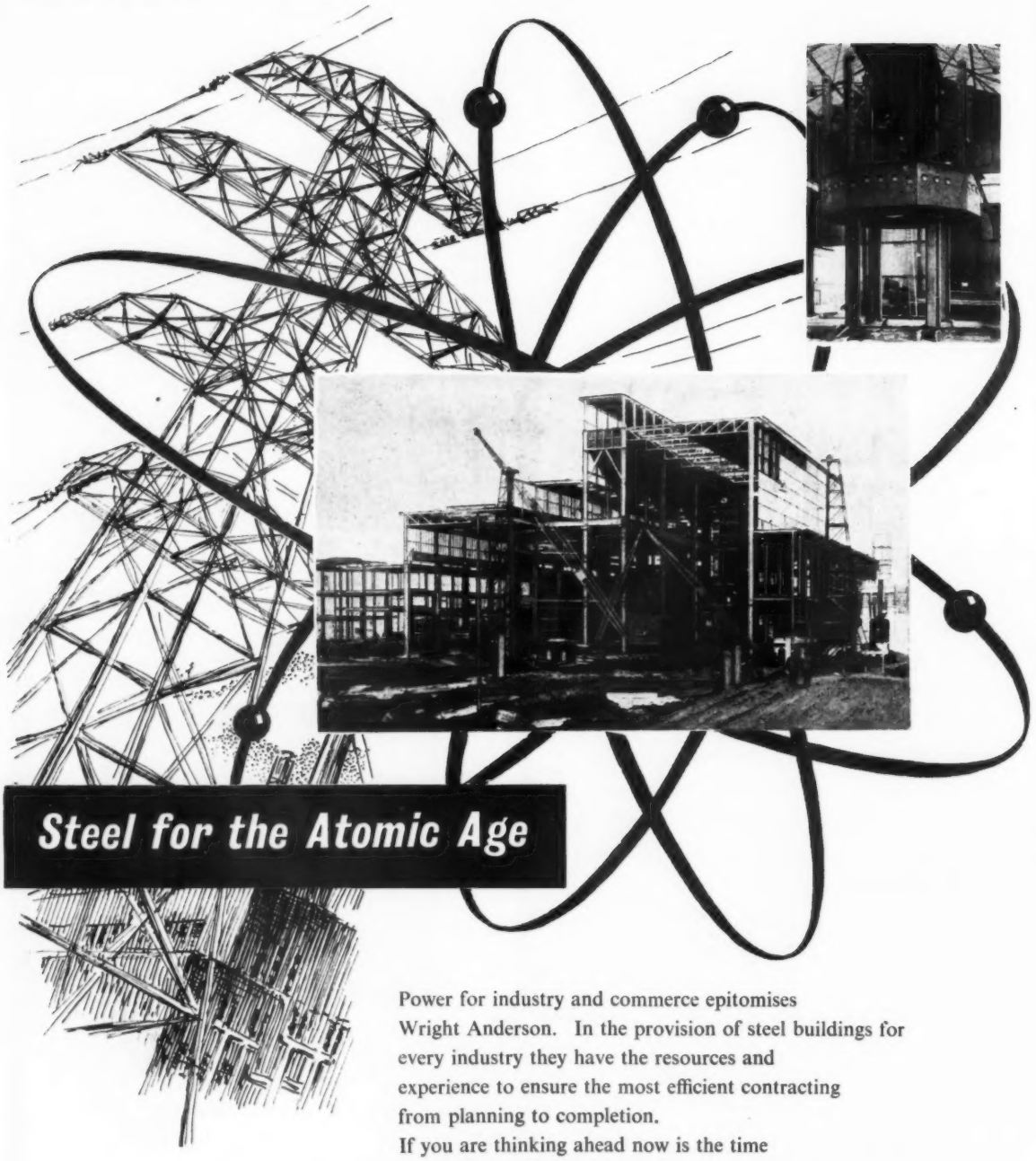

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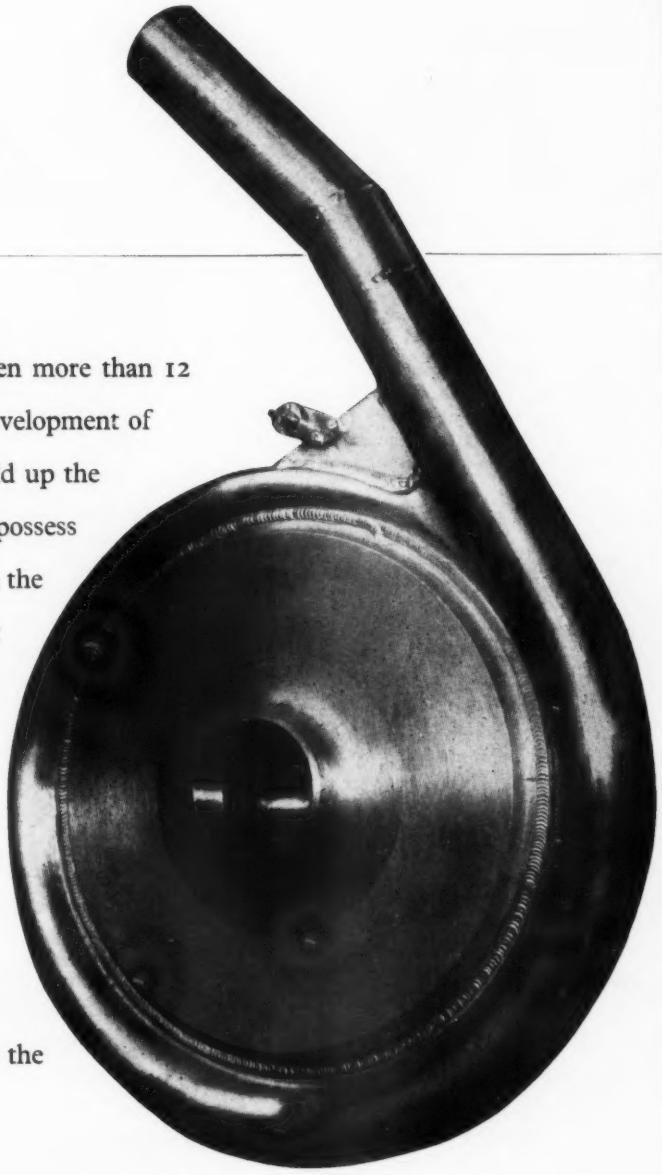

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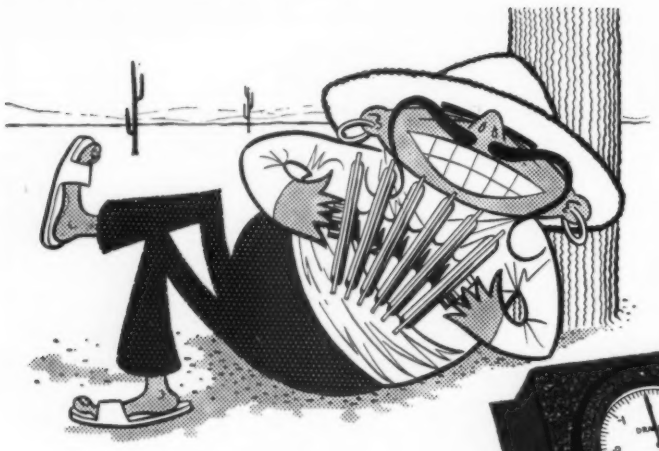

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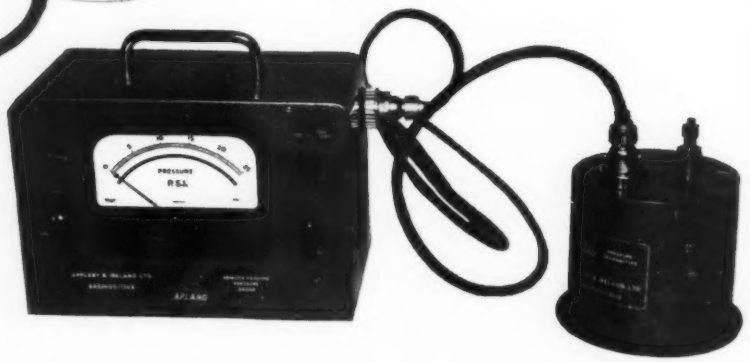

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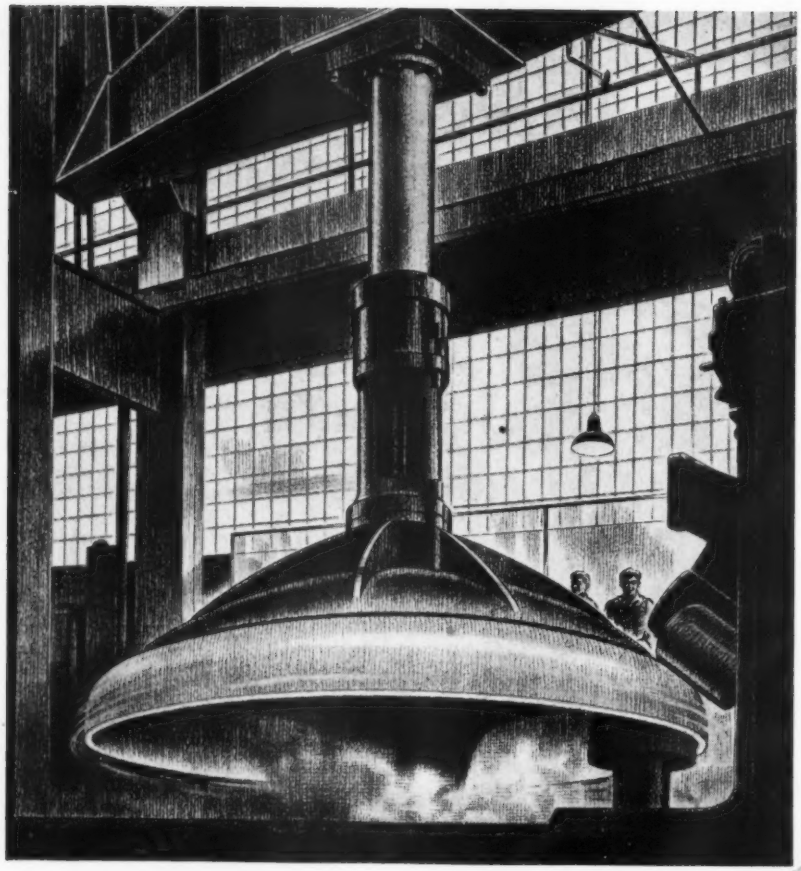

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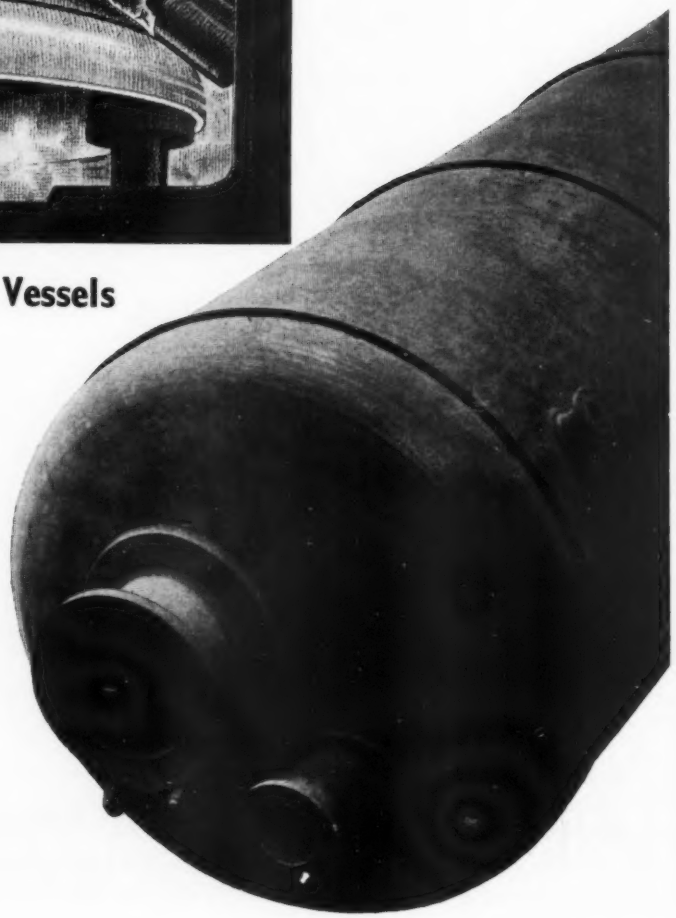

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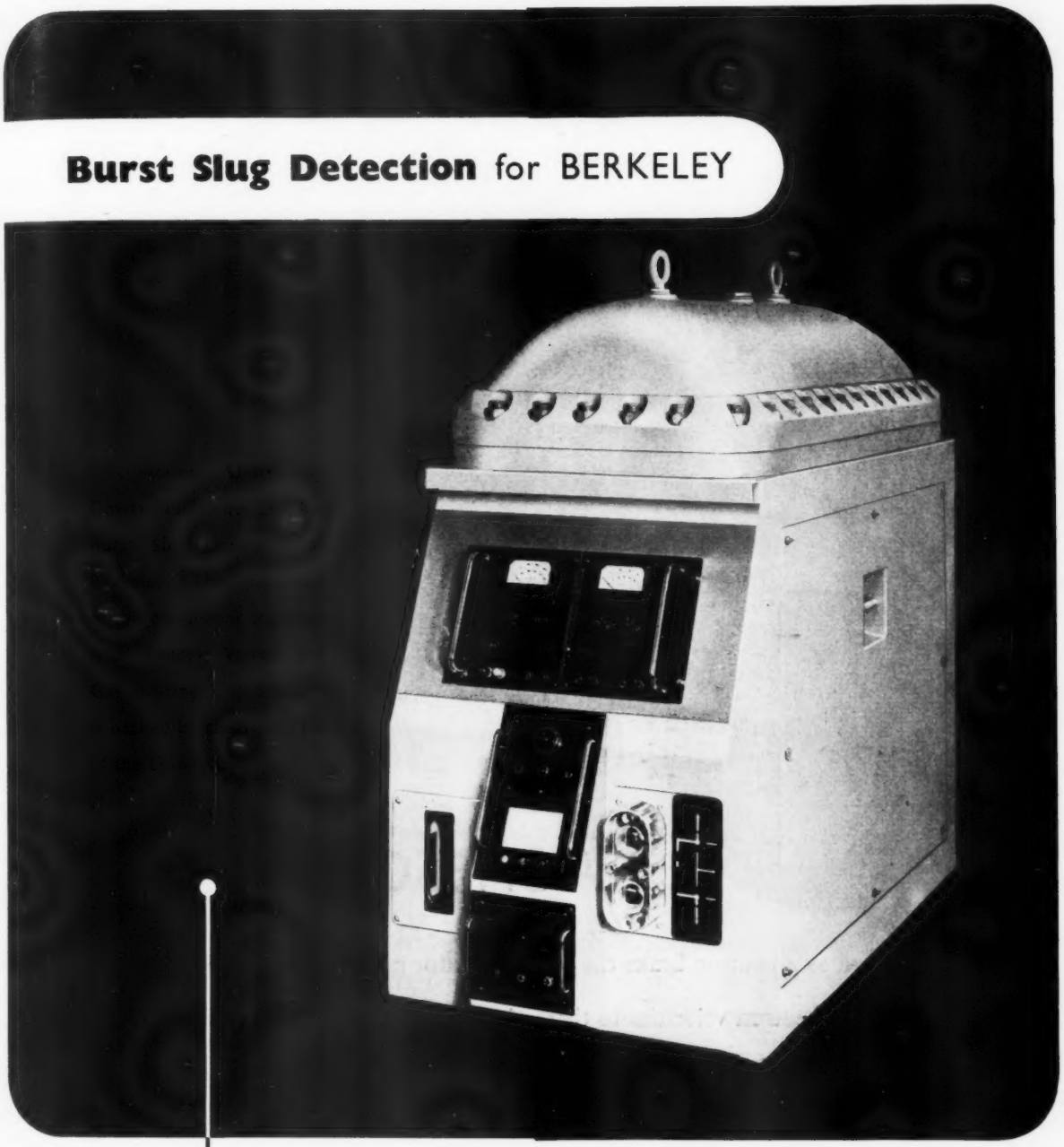

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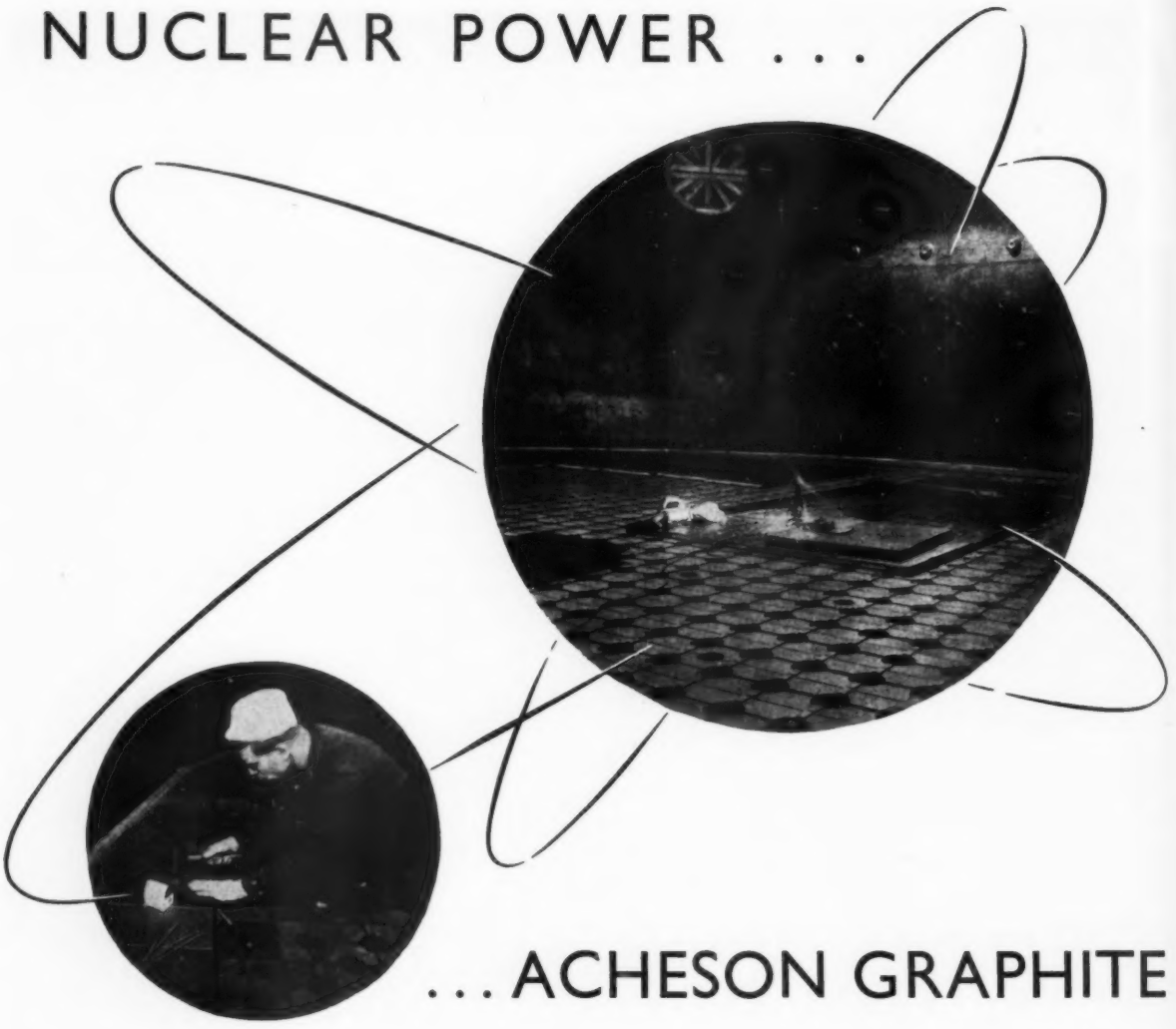

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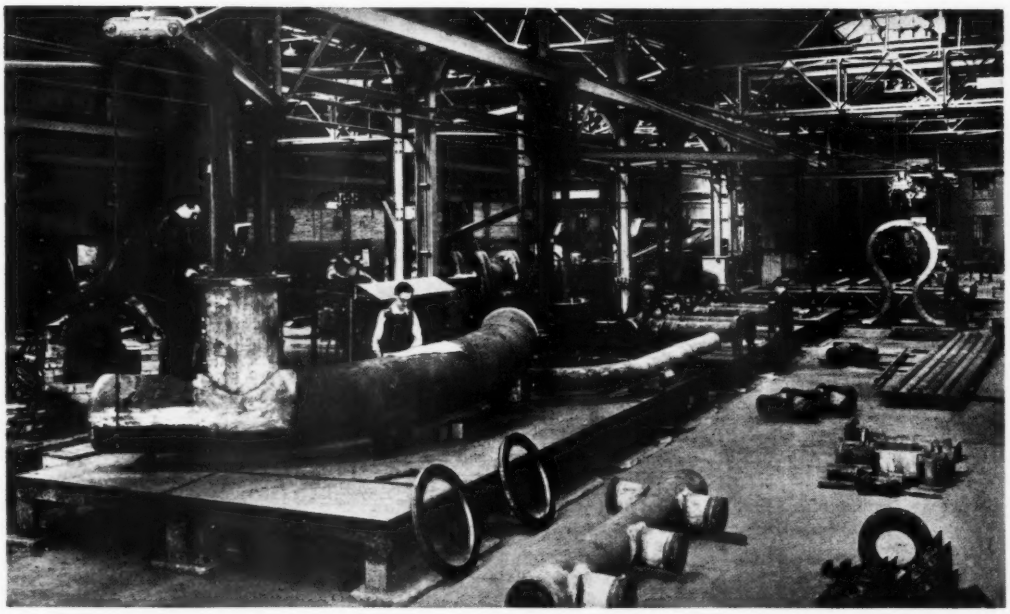

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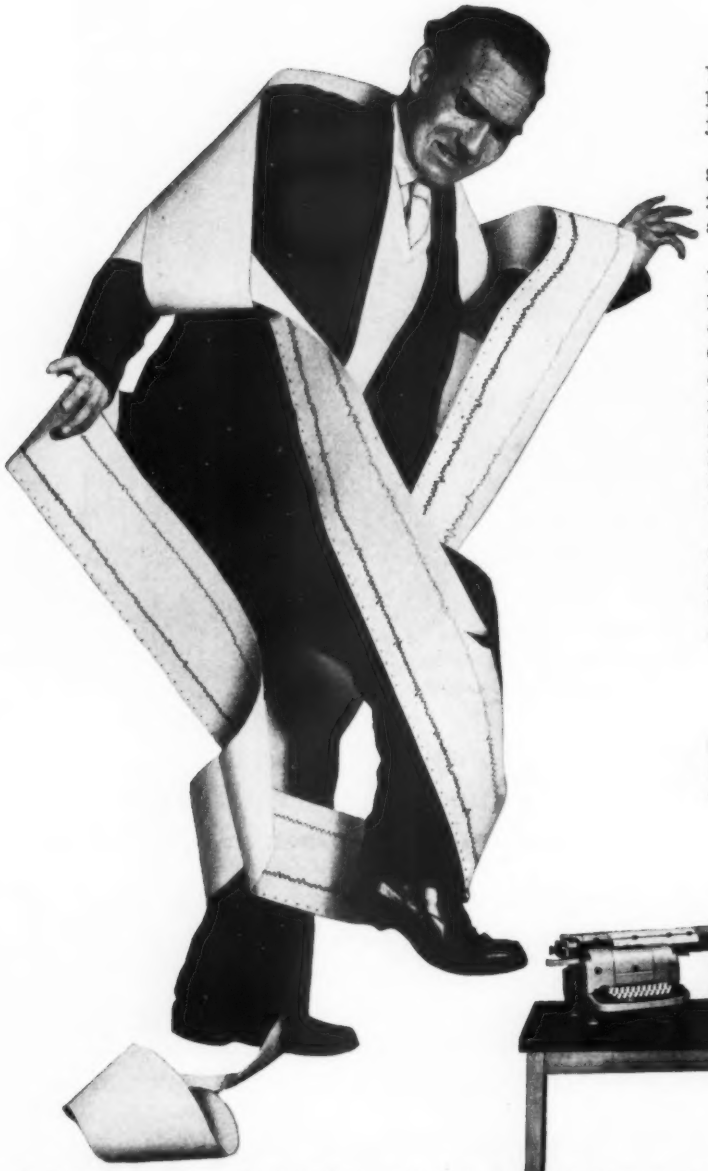

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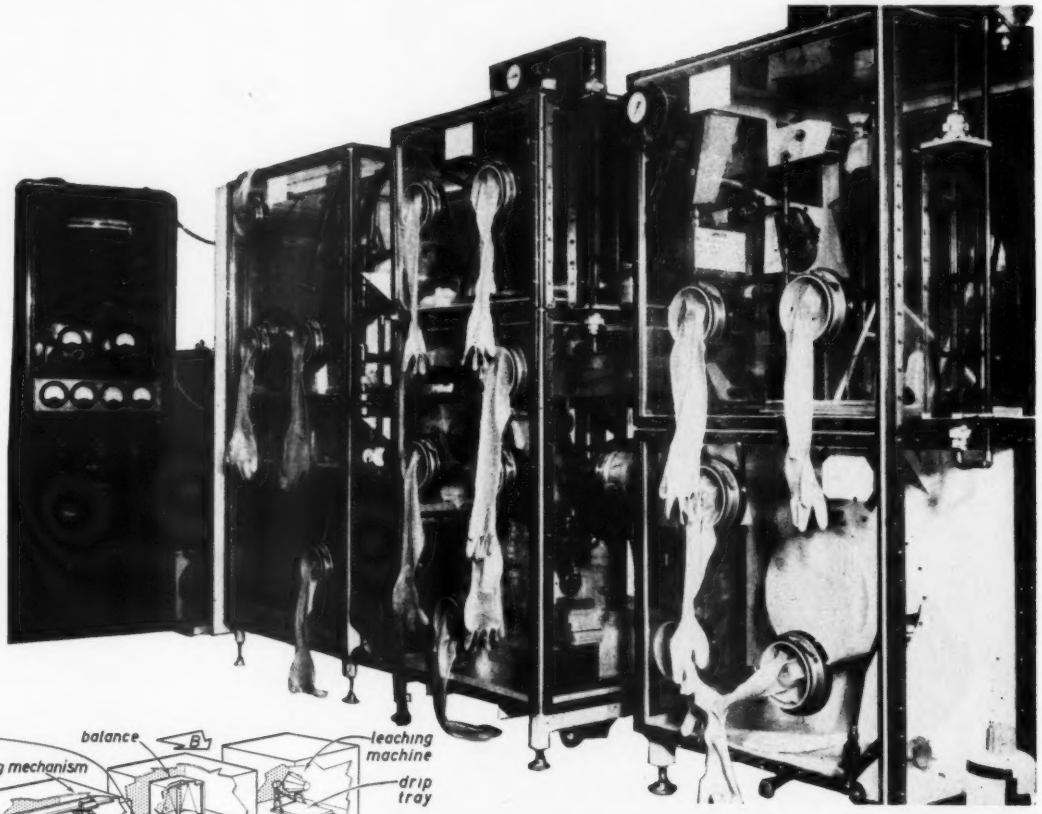
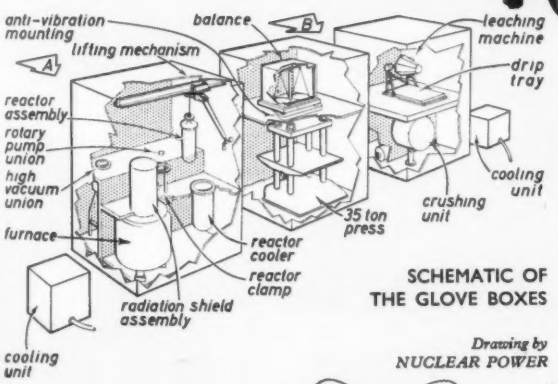


Photo by courtesy of A.E.R.E.



SCHEMATIC OF THE GLOVE BOXES

Drawing by NUCLEAR POWER

A SUITE OF GLOVE BOXES FOR EXPERIMENTAL PRODUCTION OF U-233 METAL

- Consulting engineers
- Designers and manufacturers of nuclear and specific prototype equipment
- Remote manipulation equipment
- Vacuum casting equipment
- High vacuum equipment
- Electronic engineers
- Radio frequency engineers
- Low temperature refrigeration
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WESTERN DETAIL MANUFACTURERS LTD

WESTERN WORKS, STAPLE HILL BRISTOL telephone 65-6141/42/43 cables and telegrams: Aries, Bristol, England

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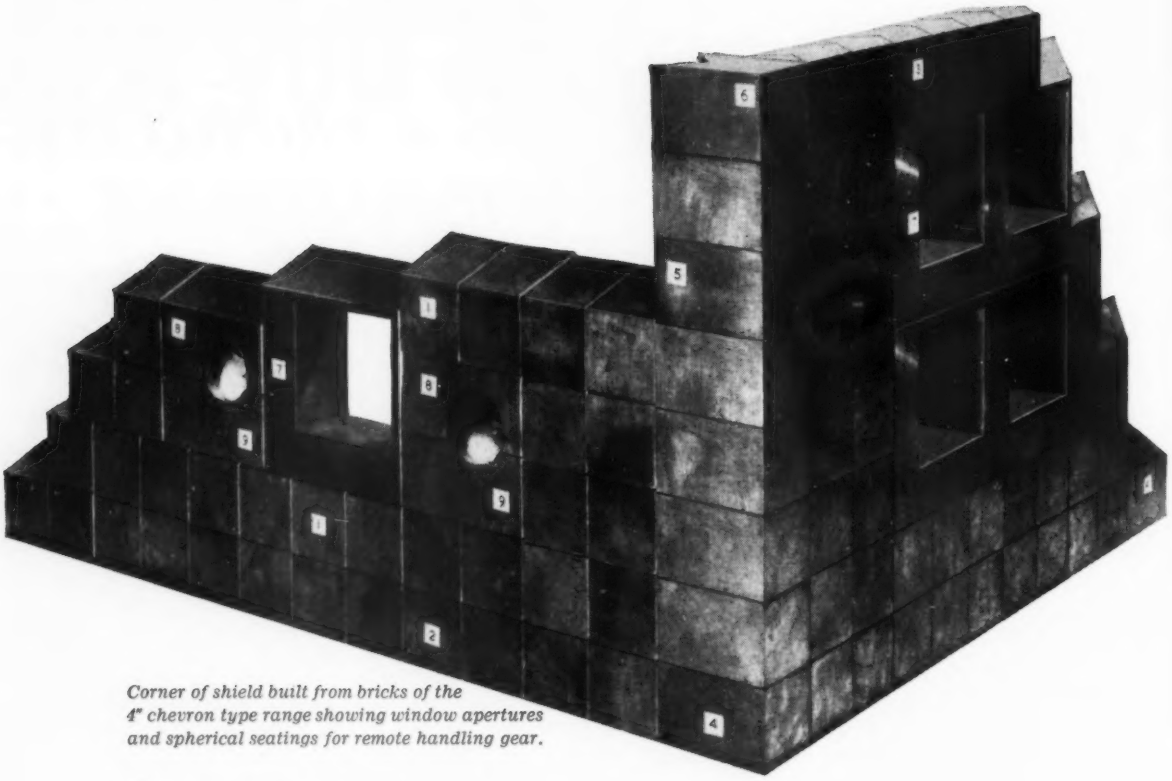
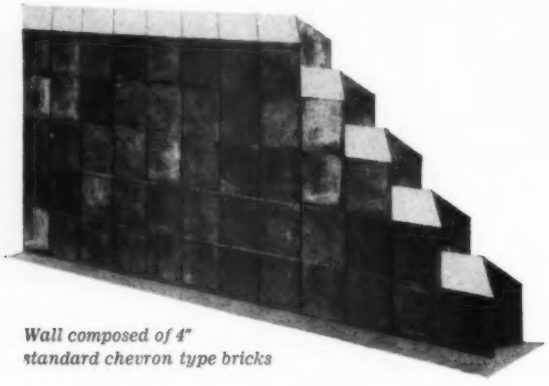


Corner of shield built from bricks of the 4" chevron type range showing window apertures and spherical seatings for remote handling gear.



Wall composed of 4" standard chevron type bricks

LEAD SHIELDING

Some of the lead bricks we supplied to the United Kingdom Atomic Energy Authority are shown in these photographs. The people to consult about the production of special shapes for shielding are Associated Lead.

ASSOCIATED LEAD

MANUFACTURERS LIMITED

CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2
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LEAD WORKS LANE, CHESTER

EXPORT ENQUIRIES: ASSOCIATED LEAD MANUFACTURERS EXPORT CO. LTD., CLEMENTS HOUSE, 14 GRESHAM STREET, LONDON, E.C.2

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POLLARD

SOLID & FLEXIBLE ROLLER BEARINGS

Full range of Solid and Flexible Roller Bearings available from 10 mm. to 350 mm. shaft diameter. Ask for catalogue *RFX*
High capacity Max-Load Roller Bearings in a very wide range also available. Ask for catalogue *MAX*
All interchangeable with and equivalent to bearings of American type and manufacture.

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FERRYBRIDGE, KNOTTINGLEY, YORKS. Tel: Knottingley 2323

London Office: 44 Hertford Street, London, W.1. Tel: Legation 3888 Telex: 23549

POLLARD BEARINGS (Northampton) LTD., Countess Rd., Northampton. Tel: 3766 Telex: 31-624

CANADIAN POLLARD BEARINGS LTD., Oakville, Ontario. Tel: VI.5-1667

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Have you a problem in remote handling?

If so, we can help you!

We have already been entrusted with the manufacture of the following equipment :-

Remote Control Machines for Element Handling

★ **REMOTELY CONTROLLED LATHES—**
For producing test pieces from enriched uranium elements.

★ **X-RAY MACHINES & CASSETTE MECHANISMS—**
For X-raying irradiated fuel elements by remote means.

★ **END REMOVAL AND STRIPPING MACHINES—**
For removal of the nose and tail units and stripping of the stainless steel Sheaths from the elements.

★ **SEPARATION MACHINES—**
For separating the fuel elements from the breeder elements.

★ **GENERAL-PURPOSE CUTTING MACHINES—**
For removal, by slitting, of the stainless steel Sheaths from the elements and for slicing up of uranium elements.

★ **ELEMENT RECANNING MACHINES AND OPERATING GEAR—**
For recanning used uranium fuel for transport purposes.

Machined Components and Assemblies

★ **CRUSHING PRESSES—**
50-ton presses for crushing uranium elements for subsequent test purposes.

★ **ZINC BROMIDE VIEWING WINDOWS—**
For irradiated fuel element laboratories.

★ **SERVICE SLEEVES—**
For manipulators, electrical and hydraulic controls.

★ **COOLANT CHANNEL GAG ASSEMBLIES**

Having the most comprehensive engineering plant in the South, we can offer complete design and manufacturing facilities for all types of remote control equipment and precision machining of components and assemblies.

We thus take responsibility from inception, through design, manufacture and installation.

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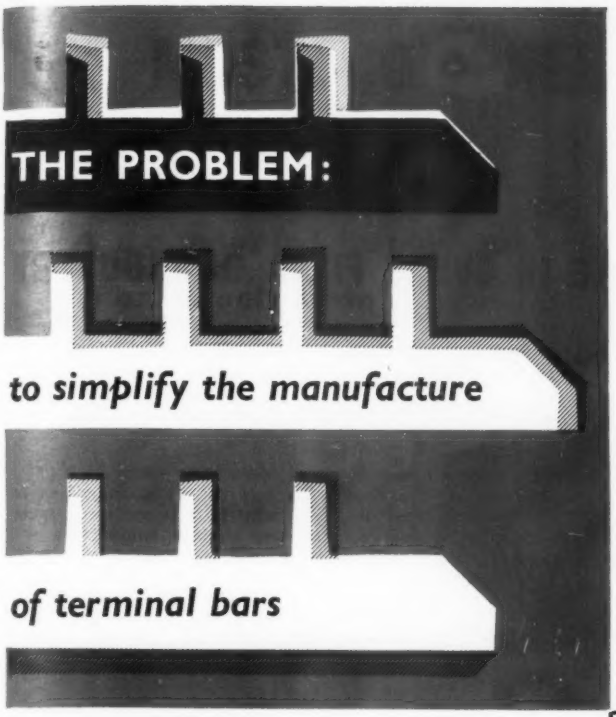
MARCYN WORKS - GOLDSMITH AVENUE
PORTSMOUTH

Tel.: 32233-6 (4 lines) **Grams: "Marcyn, Portsmouth"**

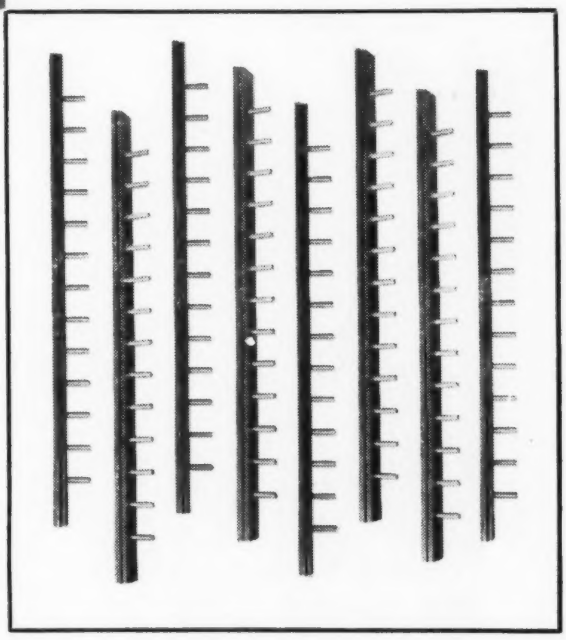


Forty-two of these terminal bars are used in each of the control equipments of the diesel electric locomotives now being built as part of the modernisation plan of British Railways. The builders are Brush Traction Ltd. Traditional methods of terminal bar manufacture from laminated sheets involve twenty-eight separate drilling operations. To simplify production Brush sought a new method — and found the answer in Shell's "Epikote" Resins.

THE ANSWER:

casting in Epikote Resins

The moulding material used is a mixture of "Epikote" Resin 828 and "Epikure" MPD (metaphenylene-diamine). It is cured at 100°C for one hour and no post-curing is required. The terminal bolts are bonded exceptionally strongly into the resin blocks and drilling is eliminated. These bars do not warp. They have come through all tests with flying colours — mechanical strength tests of 10,000 lbs. p.s.i.; insulation tests at 2kV. Here, as in many other applications, Epikote Resins produce a better component quicker, and at less cost.



EPIKOTE EPOXY RESINS

solve many production problems

SHELL

SHELL CHEMICAL COMPANY LIMITED. *In association with Petrochemicals Limited · Styrene Products Limited*

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S.S. 17.

"EPIKOTE" *and* "EPIKURE" *are Registered Trade Marks*

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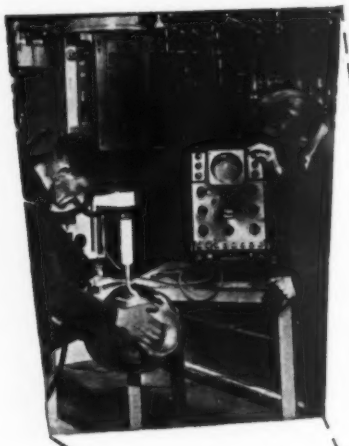
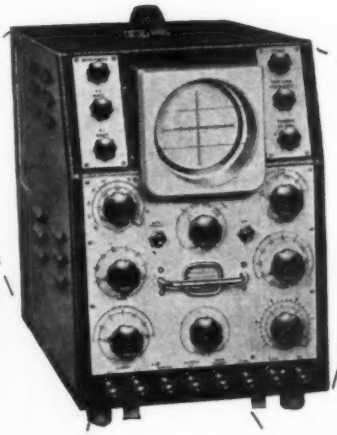


INVALUABLE IN EVERY FIELD OF INDUSTRY



COSSOR OSCILLOGRAPHS

Trial-and-error methods of fault evaluation are outmoded, inaccurate and expensive. With a Cossor Oscillograph, the modern Engineer is armed with an instrument that will display, measure and time the action of his electrical or mechanical machinery with precision, speed and certainty. It is worthwhile, therefore, to investigate the possibilities of these versatile instruments in *your* Industry by writing to:

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THE MOST COMPREHENSIVE MEASURING OSCILLOSCOPE SYSTEM AVAILABLE?

- **d.c. coupled throughout**
- **extremely wide range**
- **'infallible' time base triggering**
- **transients retained indefinitely for detailed examination**

After 10 years experience in the manufacture of multi-channel oscilloscopes—culminating in the equipment supplied for the A.E.R.E. ZETA project—we are able to offer 'unitized' equipment of an advanced design. The instruments are not intended for *indicating* results—the performance raises the oscilloscope to a new level as a *measuring* tool for the research worker.

By interconnection of suitable units as listed below (all units are on standard rack panels), an extremely versatile instrument is obtained, based on 20th Century D6B Sq. double gun cathode ray tubes, or 'Memotron' storage tubes, and consisting of any number of channels from two upwards.

The tubes are suitably arranged for photography.

Unit letter	*Function*	*Panel Height*
A*	2-Channel display (one double gun tube)	10½″
B*	4-Channel display (two double gun tubes)	14″
C*	8-Channel display (four double gun tubes)	19½″
D†	1-Channel display (one Memotron storage tube)	14″
E	2-Channel display (two Memotron storage tubes)	14″
F	2-Channel X and Y Amplifiers	5¼″
G	4-Channel X and Y Amplifiers	10½″
H	Single Scan Generator and Time/Voltage Calibrator	10½″
I	Double Scan Generator and Time/Voltage Calibrator	10½″
J	Variable 2-6 kV. Stabilized E.H.T. Supply for up to four double gun tubes	5¼″
K	Variable positive and negative 3 kV Stabilized E.H.T. Supply for up to two Memotron storage tubes	10½″
L	Type A Stabilized H.T. Supply	10½″
M/2–8	Balanced attenuator panel for 2-8 Channels	10½″
N/0·1–2	Signal delay panel for one channel; delay fixed at 0·1 up to 2 microseconds	5¼″
O	2-Channel Y Pre-amplifier	5¼″
P	4-Channel Y Pre-amplifier	5¼″

*Combined as required to produce more than 8 Channels.
†Has the property of retaining the trace indefinitely until erased.

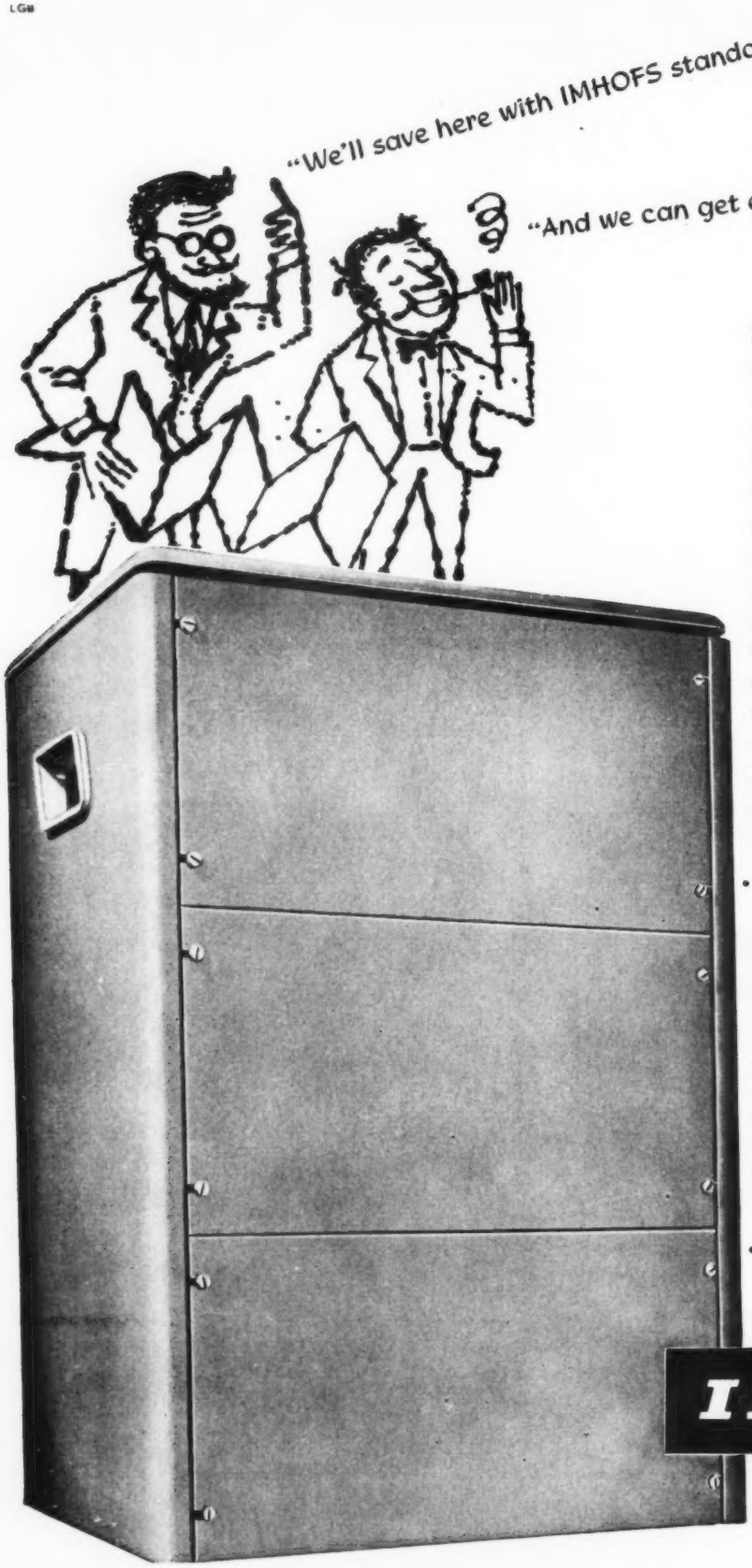
Example of a typical 8-Channel instrument.
Units C, two of G, H or I, J, four of K, M/8, and say, N/0·5 and two of O.

Example of a 2-Channel Storage Oscilloscope.
Units E, F, H, K and L.

A. E. CAWKELL, ELECTRONIC ENGINEERS

6-8 VICTORY ARCADE, SOUTHALL, MIDDLESEX

(Tel: Southall 3702/5881)



SAVE — and sell — with Imhofs standard metal cases. Nine times out of ten an Imhof standard case will exactly suit your requirements. They are precision built from fine materials and beautifully designed and finished. Many companies in the Nuclear industry regard Imhofs as their case factory, and enjoy all the benefits of quantity production and rapid delivery with none of the worry! Write now for catalogues and full details of this specialist service, which includes a wide range of standard cases, raks and consoles, and any metal housing built to order.

OVER 50 STANDARD CASES

supplied in quantity ex stock

There's a case for every job in the Imhof standard range. Order as you want them—delivery of any size or number ex stock in 7 days. Even sooner if really necessary! *Special terms for quantity orders.* A full range of handles and accessories also supplied.

FOR CASES IT'S

IMHOFS

ALFRED IMHOF LIMITED
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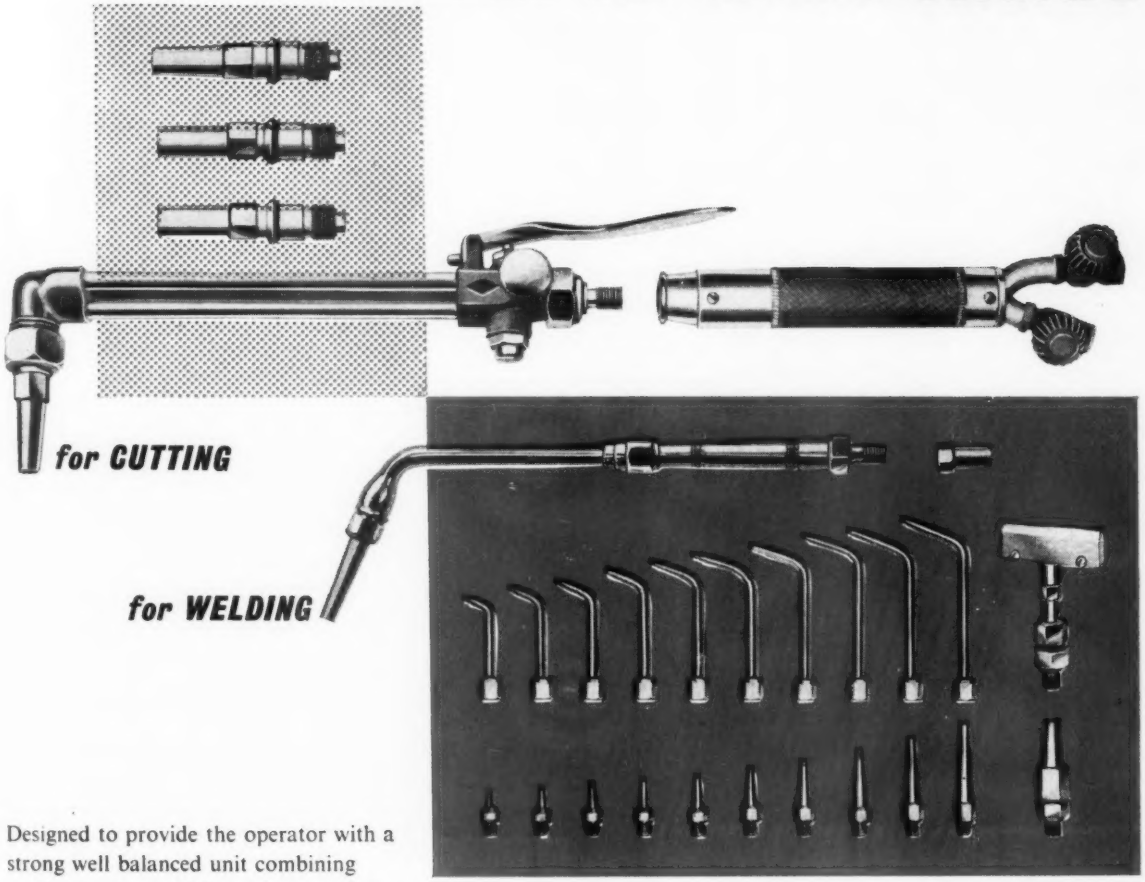
maintaining ***B.I.G.*** *excellence*

COMBINED WELDING AND CUTTING BLOWPIPE



Designed to provide the operator with a strong well balanced unit combining maximum power with maximum safety.

Based on many years' practical experience, design of B.I.G. cutters incorporates the following unique features:

Cupro nickel gas tubes

Silver solder joints

Nozzle mixing of gas which is best deterrent to flashback

One-piece solid copper nozzle

Special high pressure oxygen seats

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. . . and built to ***B.I.G.*** *standards*

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Sales and Technical Assistance available in most areas

Rainbow 1754

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2

of the four new

Nuclear Power Stations

now under construction

in the United Kingdom

will be completely equipped with

Weir

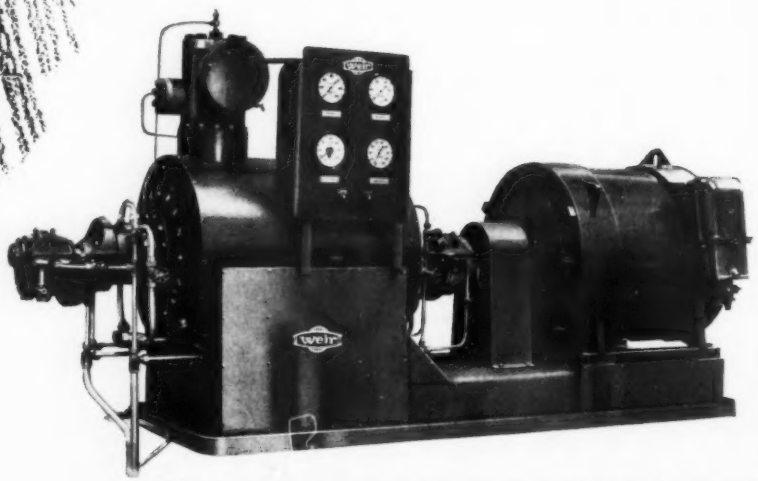
BOILER FEED PUMPS

HUNTERSTON

Twenty Weir Electrofeeders will be supplied to the order of Simon-Carves Ltd. for the high-and low-pressure circuits in the steam raising units at Hunterston. The main high-pressure units will discharge 447,600 lb./hr. at 800 lb./sq. in. and the auxiliary high-pressure units 57,250 lb./hr. at 772 lb./sq. in. The main low-pressure pumps will discharge 658,300 lb./hr. at 323 lb./sq. in. and the auxiliary low-pressure pumps 85,000 lb./hr. at 264 lb./sq. in.

BERKELEY

Six Weir Electrofeeders, each with an output of 1,000,000 lb./hr. at 500 lb./sq. in. and two Weir Electrofeeders each having an output of 66,000 lb./hr. at 410 lb./sq. in. have been ordered by John Thompson (Water Tube Boilers) Ltd., for the Berkeley nuclear power station.



This is only a part of the major feed pump work in hand for the electricity supply industry in this country and overseas, for nuclear and conventional fuel stations.

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to CALDER HALL

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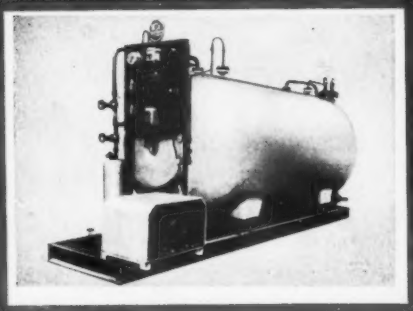
A full technical service is available on the installation of storage tanks, and on all other aspects of the handling, distribution, and use of carbon dioxide.



Without effort and without loss, I.C.I. carbon dioxide, which meets the exacting requirements of the U.K. Atomic Energy Authority, is always on tap, where and when it is wanted.

Full information on request

IMPERIAL CHEMICAL INDUSTRIES LIMITED, LONDON, S.W.1

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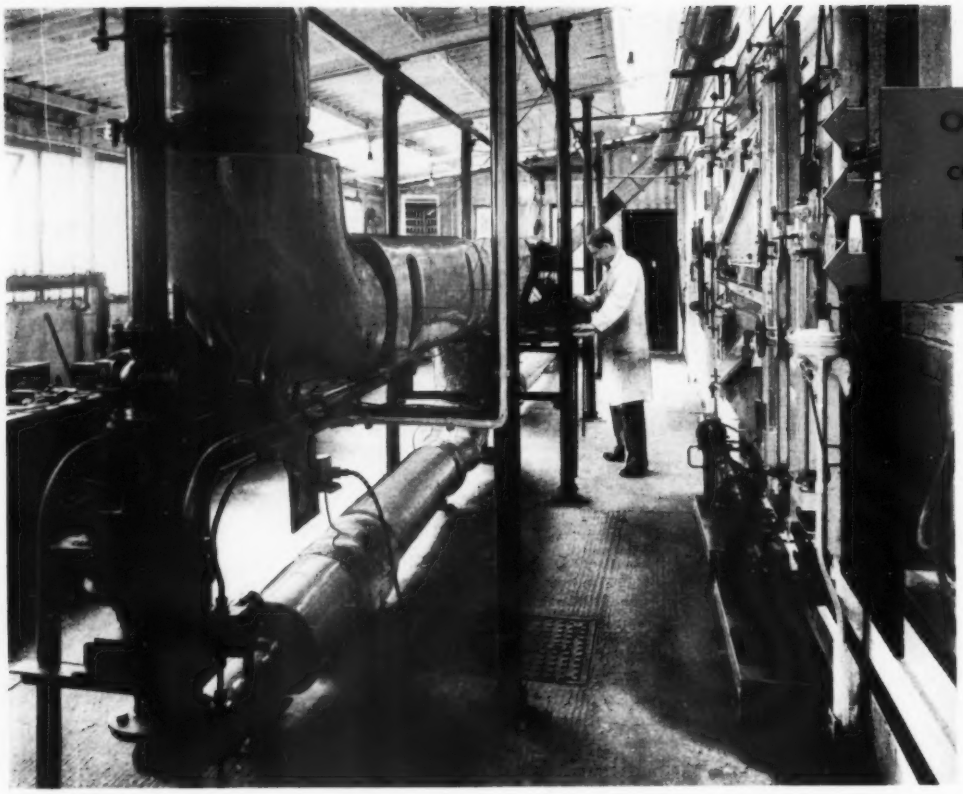

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We have comprehensive research and development facilities including a Pressure Test Rig.

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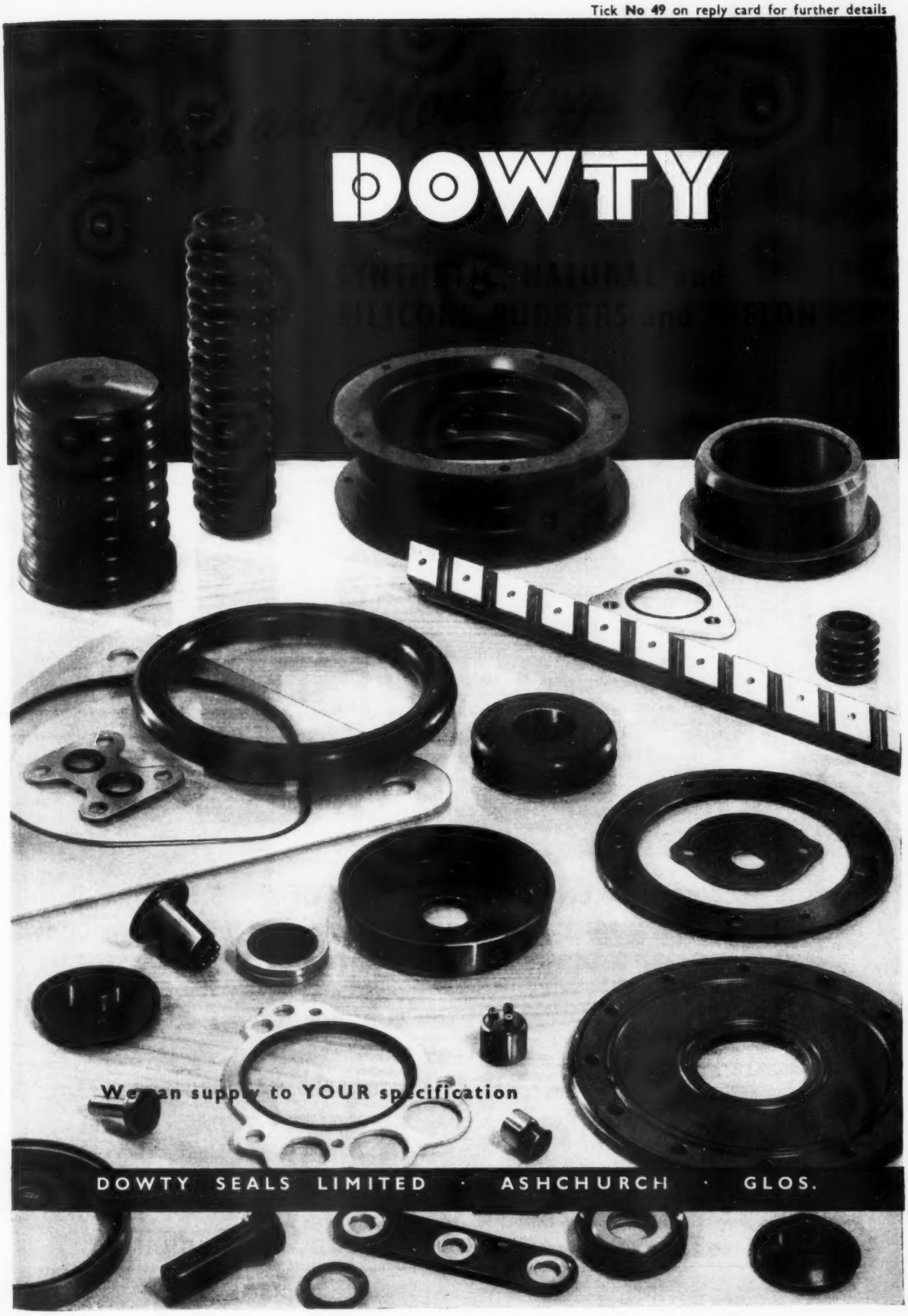

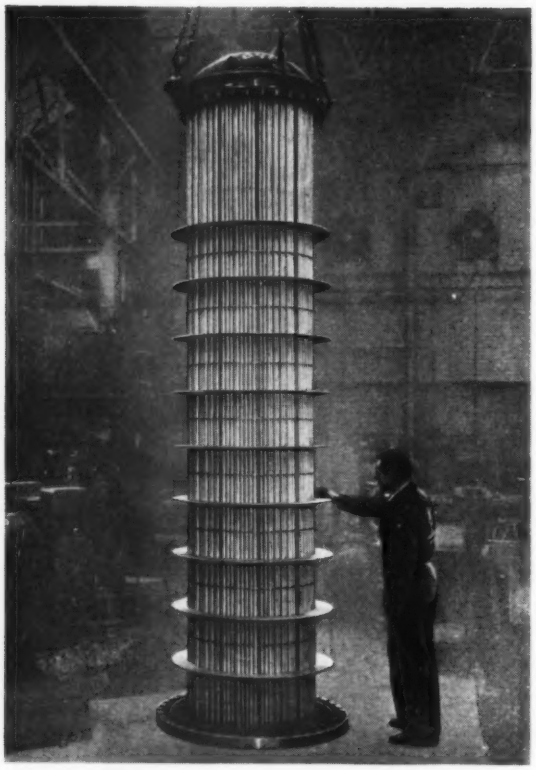

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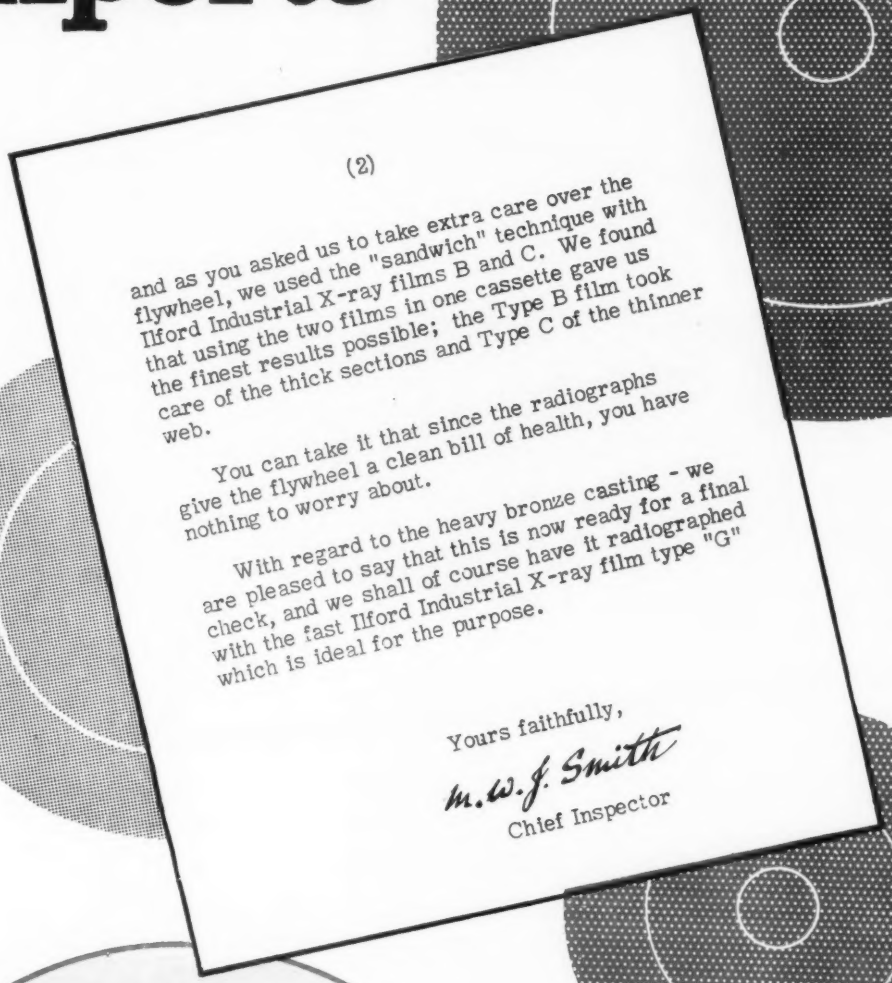
Between experts



(2)

and as you asked us to take extra care over the flywheel, we used the "sandwich" technique with Ilford Industrial X-ray films B and C. We found that using the two films in one cassette gave us the finest results possible; the Type B film took care of the thick sections and Type C of the thinner web.

You can take it that since the radiographs give the flywheel a clean bill of health, you have nothing to worry about.

With regard to the heavy bronze casting - we are pleased to say that this is now ready for a final check, and we shall of course have it radiographed with the fast Ilford Industrial X-ray film type "G" which is ideal for the purpose.

Yours faithfully,

M. W. J. Smith

Chief Inspector

ILFORD

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FOR INDUSTRIAL RADIOGRAPHY

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. . . DENIS TAYLOR, M.SC., PH.D., M.I.E.E., F.INST.P. REVIEW ARTICLE "NUCLEAR POWER YEAR BOOK" 1957-58.

As originators and sole manufacturers of the Dekatron, and having developed most of its associated circuitry, we feel that we know best how to put it to work to meet your requirements. Many of our instruments (one of which is illustrated) are already making an effective contribution to production and process control by counting, batching, timing and measuring with complete reliability and often with little or no supervision.

Make sure you get the best by appointing Ericsson as your complete supply for source

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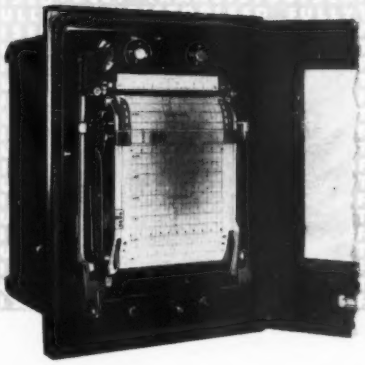
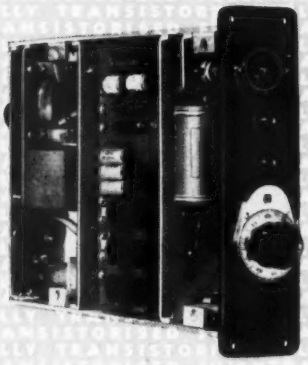
E.79B-62

THE BAILEY *New* EQUIPMENT

Bailey high precision transistorised 5 in. Strip Chart Recorder





Bailey high precision transistorised controller Model WBOT designed to operate as an ON/OFF controller or alarm unit

FULLY TRANSISTORISED

STRIP CHART RECORDER · TWO-POSITION ALARM
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INSTRUMENTS AND CONTROL SYSTEMS FOR THE POWER AND PROCESS INDUSTRIES

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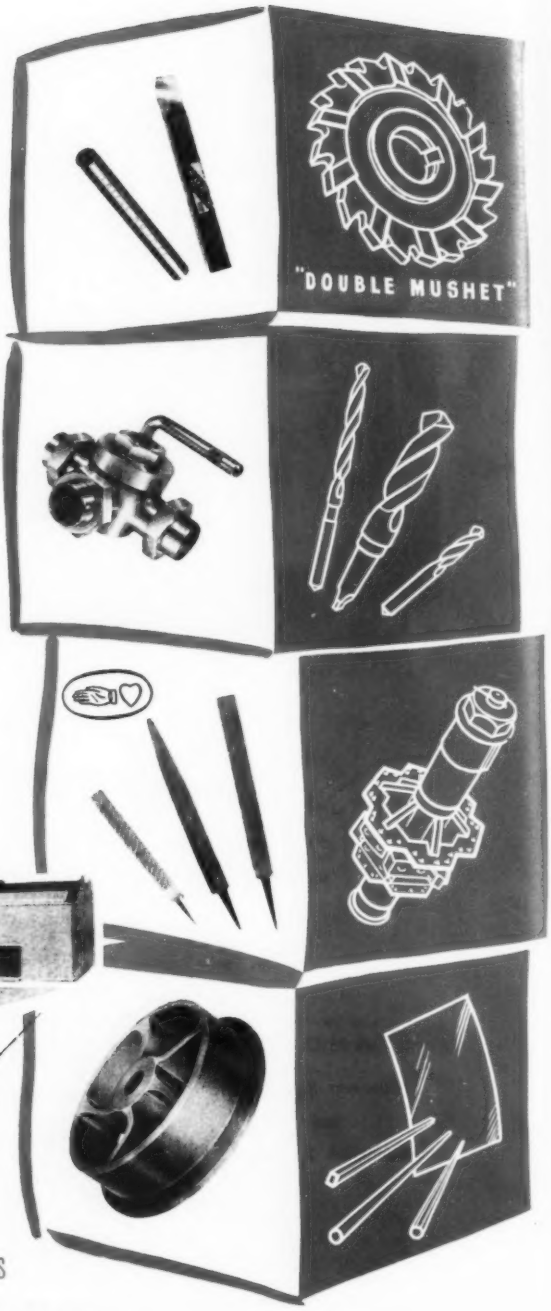
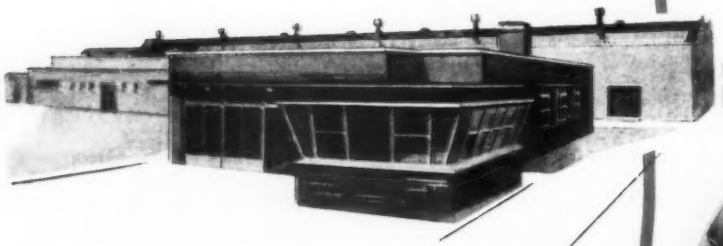
Products in alloy, stainless and tool steels are manufactured throughout within the same organisation, and include castings by general foundry and precision methods, forgings and engineers' cutting tools, etc.





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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING

APRIL 1958 VOLUME 3 NUMBER 24

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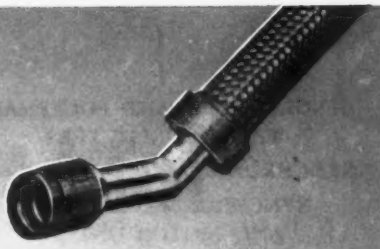

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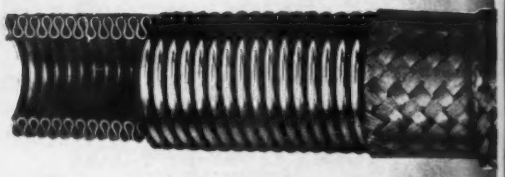

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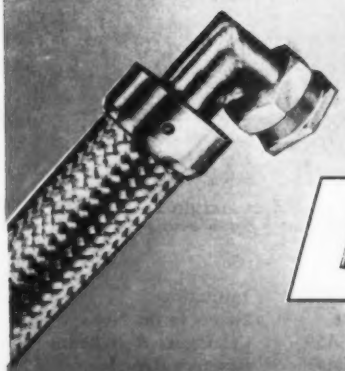

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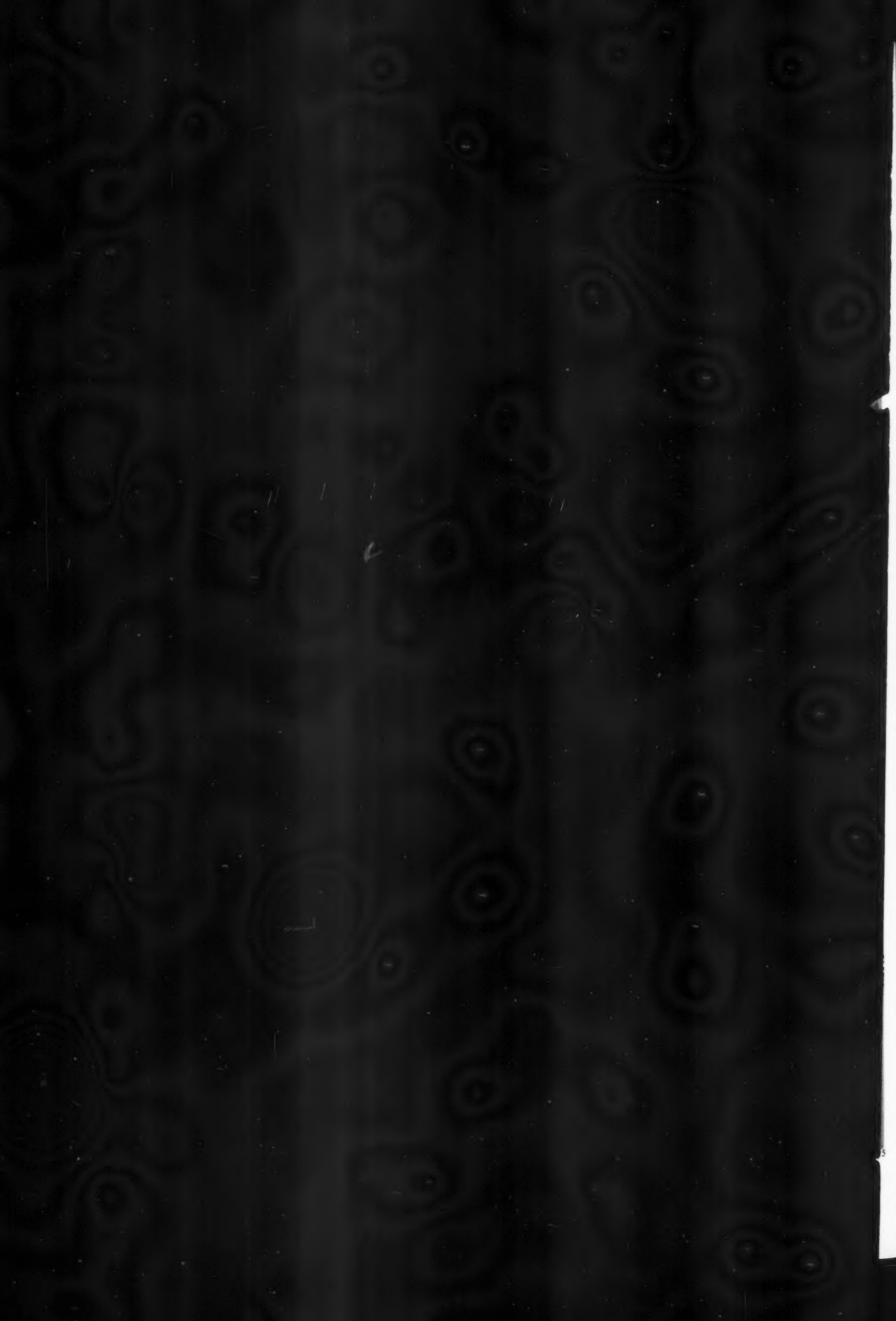

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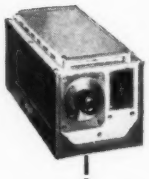

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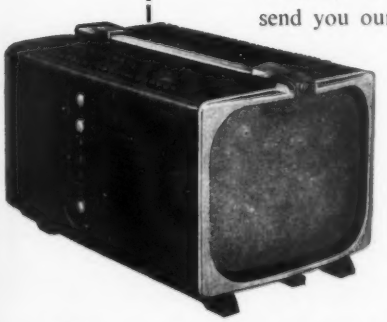

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Publishers Column

We're honoured

Everybody, we feel pretty safe in asserting, loves a show—even when it's connected with their work—and exhibitions certainly provide a wonderful opportunity for engineers and scientists to get together and exchange ideas. Not, of course, that this is the main object of the operation—that is the furtherance of business and trade. In this issue we carry extensive previews of two such shows—the long-established Physical Society Exhibition and the sprightly young Instruments, Electronics and Automation show. These previews are not easy to arrange since we have to have the information many weeks before the exhibition begins, and in many cases firms don't even know at that time what they intend to show. However, by dint of methods approaching third degree, we have managed to get nearly all the highlights of these exhibitions.

We, on NUCLEAR POWER, feel very proud at being invited to take part in the exclusive Physical Society show this year and we are determined to make our stand a credit to the exhibition. Of course, manning an exhibition stand makes severe inroads into the time of our staff and this can be awkward as the magazine must keep coming out no matter what. Nevertheless we hope to have some editorial staff on the stand at the Horticultural Hall all the time so that our visitors' questions on NUCLEAR POWER can be answered.

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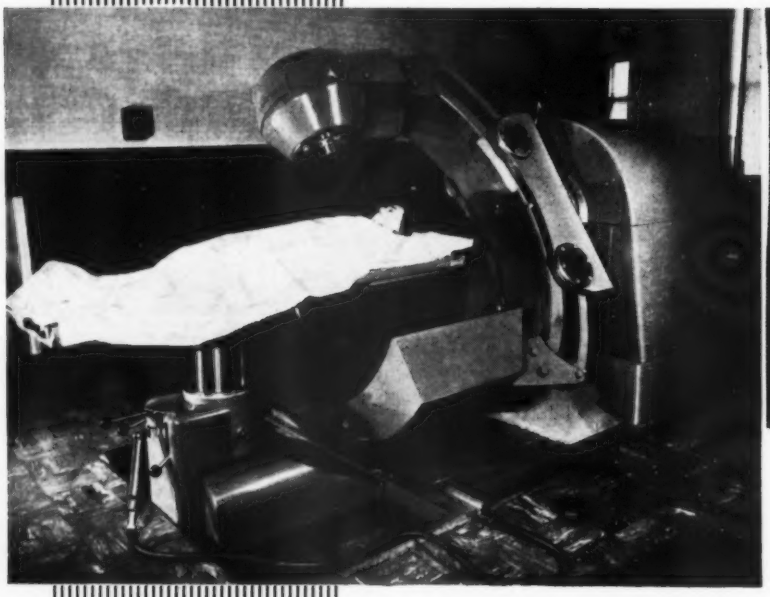

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G.E.C.

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Vision needed

SIR: The whole idea of the nuclear powered plane is quite fantastic. No doubt if sufficient effort were devoted to it a suitable reactor could be developed and some progress might even be made on the problem of lightweight shielding but even then all you would have would be a plane with unlimited range coupled with appallingly poor take-off and climb. Maintenance would be extremely difficult and the consequences of a crash really too horrible to contemplate.

Hayes, Middx. P. S. J. DARWEN

▶ *It's very easy to be blimpish about the plane project but it would be wrong in our opinion to discourage people who want to work on it. After all, in* 1903 *how many foresaw to what extent aviation would come to alter our lives? As a matter of fact the nuclear plane is probably not so very far away. The Americans have operated a reactor installed in a plane and they have also run on the ground a reactor which could power a plane: it is obviously not now a very big step to link these. Certainly the crash problem in particular and the shielding question in general are very severe, but while one obviously cannot rely on it, it would be as well not to exclude the possibility of some completely unforeseen discovery which might transform the whole situation. This sort of thing has happened before. Ed.*

Electricity from fusion

SIR: It has repeatedly been said by various authorities that if thermonuclear fusion proves controllable it may be possible to generate electricity direct without the complication of a thermodynamic cycle. I would like to know how this could be done.

Tel-Aviv, Israel M. FINE

▶ *The thing seems to be possible in principle although it is not at all clear at this stage just how the details would be worked out. The products of a thermonuclear fusion between deuterium nuclei—helium-3 or tritium —have a very considerable amount of kinetic energy. Furthermore they are charged and are so unable to escape from the electromagnetic field confining the hot plasma. Thus it may be possible to make these charged moving particles induce a current in the coils and so lead to the direct production of power. Ed.*

Insurance tariffs

SIR: In your editorial last month—'Specified Perils'—you touch on the question of premiums for the insurance cover of nuclear power stations. How will these be determined by the insurance companies who, as far as I can see, have extremely little to work on?

London, E.C.2 B. J. CARVER

▶ *This is one of the big questions of the day and it is not easy to give a straightforward answer at this stage, although it has considerable bearing on the probable unit cost of nuclear electricity. At the beginning of March, the British Insurance Association held an international conference in London at which problems of atomic plant insurance were discussed by experts. On the question of premiums, however, the conference stuck, and decided to set up a special committee to go into this in Paris in April. The only specific case we can recall is that of the Commonwealth Edison boiling water reactor which is now under construction at Dresden, Illinois. Third party risks up to $M50 are covered for* $250,000 *a year and the premium is said to amount to about* 2½ *pct of the cost of production of electricity. It should be emphasized that this is for third party risks only. Ed.*

Plutonium as fuel

SIR: We hear a lot in speeches about using plutonium as a reactor fuel but so far this doesn't seem to have been actually done. What is the difficulty?

Bristol S. T. FINCH

▶ *Well, it melts at only* 640°C *and before it gets to that point it undergoes five complete physical transformations. This behaviour makes it impossible to use as pure metal. However, even if it didn't have these unpleasant characteristics you still wouldn't want to use pure metal—it would be far too concentrated and the heat released in fission would be far more than could be removed with any known coolant. This argument also applies to any pure fissionable material. Thus plutonium must be diluted somehow, either with fertile material such as U-238 or an inert material, or both. Plutonium alloys with several metals and work is mainly directed to devising alloys, or ceramics, that will stand up to the high temperatures without distortion. Plutonium is of course also a highly dangerous material and is probably the most poisonous substance known. However, there is no doubt that means must be found for using it safely, not only in fast breeder reactors but also as an enriched fuel for thermal reactors. Ed.*

Customer always pays

SIR: The question raised by Mr. Connell last month of whether the Government or private industry should carry out fuel reprocessing for the commercial power stations is really only of academic interest since, whoever does it, the cost will presumably descend squarely on the shoulders of the consumer.

Stockton-on-Tees P. A. HUTCHINSON

▶ *It will certainly do that, but it is possible that the cost might vary as between one or the other. A third possibility is of course that the electricity authorities set up their own facilities. To our mind it is undesirable as a principle for the Government to continue indefinitely to indulge directly in productive activities of this nature. Ed.*

Simple research?

SIR: What struck me about ZETA and the other thermonuclear devices which were described recently for the first time is their extreme simplicity compared with equipment needed for fission research. Presumably this means that almost any country, provided it has sufficient scientists of the right calibre, can now take up this fruitful line of research since it needs so little in the way of exotic materials.

Hamburg-Altona W. DREIER

Certainly, up to the point we've reached thermonuclear research is really surprisingly simple but it should not be forgotten that we're only scratching the surface as yet and the later stages of thermonuclear research leading to power might demand apparatus of much greater complexity. For example, the Stellarator C apparatus at Princeton University is not due ready for two or three years yet. No details have been released about it but in view of the time scale it is clear that it must be pretty large and complicated. Ed.

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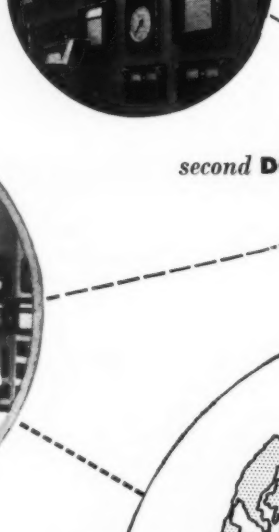

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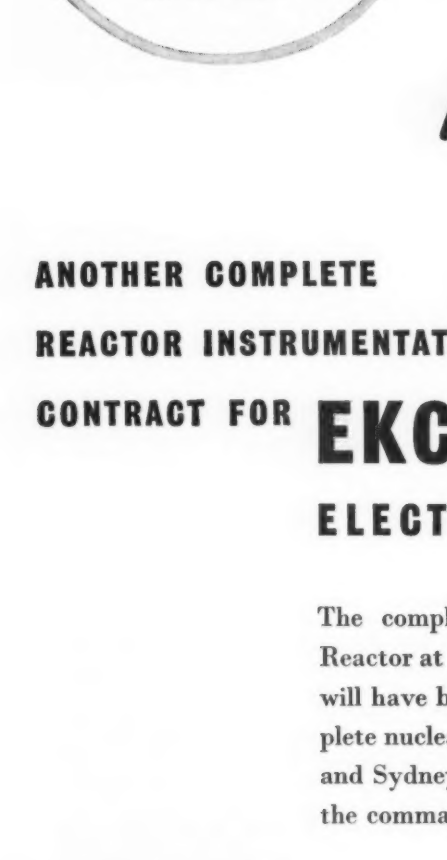

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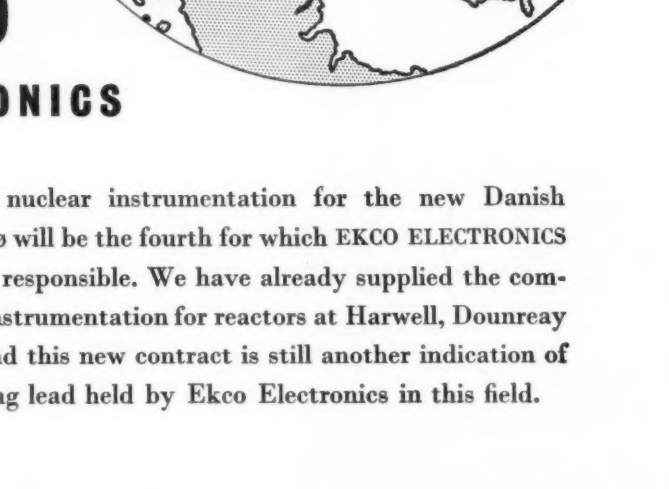

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Nuclear Power
THE JOURNAL OF BRITISH NUCLEAR ENGINEERING
APRIL 1958 VOLUME 3 NUMBER 24

Earthquakes included

There is much cause for satisfaction in the achievement of the comparatively young nuclear power industry in having secured two substantial export orders—the power stations for Italy and Japan—in the face of intense competition. At one time it looked as though, however suitable it might be for our own purposes, the Calder Hall type of power station would offer little attraction to overseas countries in view of what appeared to be a very high capital cost compared with the American type of water-cooled reactor designed to use enriched fuel. Now, however, the picture has changed somewhat. The price of Calder Hall came out pretty well exactly as estimated whereas the Shippingport PWR cost nearly twice as much. Some of this was no doubt accounted for by faulty estimation in the first place, but it now seems certain that, owing chiefly to the special metals needed, the capital cost of an American power station, particularly if built abroad, is not likely to be as low as was at one time thought.

On the question of fuel we have of course a card that cannot be trumped. Certainly the United States has been lavish in promising enriched fuel to practically any country outside the Soviet bloc that evinced interest, but these recent orders have shown that for some countries at least, when all the economic sums have been worked out it is the big gas-cooled reactor with natural uranium as fuel that wins.

This of course is not to say that there is no place for the PWR or the BWR—to do so would be to blind oneself to realities. There are many places in the world that need power but not by any means all of them need it in huge blocks. For such requirements—power outputs of from 5 to 50 MW for example—it is likely that the water-cooled reactors at present could win hands down. In fact the gas-cooled reactor simply would not be in the picture over the lower reaches of this range. This field is likely to remain an exclusive American province for a long time.

The gaining of the order for Japan—whichever company finally gets it—is particularly gratifying in view of the intense American salesmanship which has been concentrated in Tokio for a long time. It is also interesting—and perhaps even unexpected—that the Japanese earthquake experts are satisfied that the British reactor is inherently capable of meeting their stringent requirements. This should help to reinforce the already rapidly growing confidence in it as a type and lead to further orders even where earthquake resistance is not an important factor.

As with the Italian station, the Japanese intend, not unnaturally, to carry out as much of the construction work as possible, so that what they will be getting from us will be the design, technical assistance and certain specialized parts of the reactor. In a way the Italian agreement is more satisfactory since full technical collaboration between the two parties is assumed for seven years. In the Japanese case the order will be simply for one power station and there is a real danger that for future installations they might be tempted to go it alone, having acquired a certain amount of knowhow from the first station. Certainly one does not have to learn atomic energy the hard way as we did, but at the same time there is a lot to assimilate and it would be tragic if a disaster occurred through trying to run before the art of walking is mastered. However there is no country in the world that knows more about the effects of radioactivity than Japan and this will no doubt serve as a reminder of the dangers.

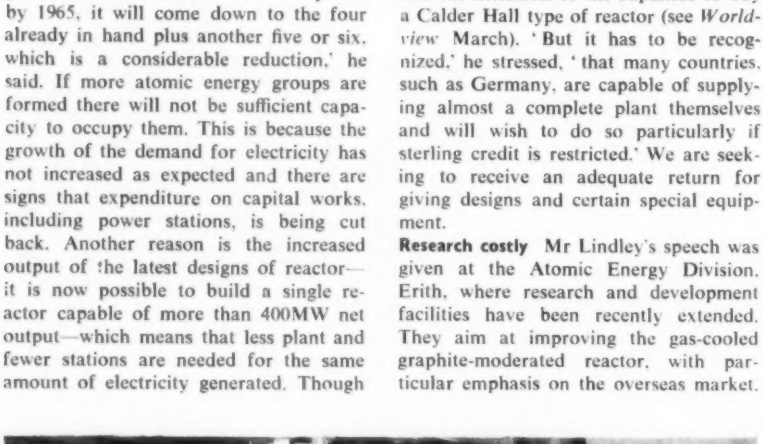
WORLDVIEW

Nuclear slow-down?

The nuclear engineering industry may soon be very substantially underloaded, warned Mr A. L. G. Lindley, assistant general manager of GEC, speaking on March 13. 'Where you would have expected 18 or 20 stations to be completed by 1965, it will come down to the four already in hand plus another five or six, which is a considerable reduction,' he said. If more atomic energy groups are formed there will not be sufficient capacity to occupy them. This is because the growth of the demand for electricity has not increased as expected and there are signs that expenditure on capital works, including power stations, is being cut back. Another reason is the increased output of the latest designs of reactor—it is now possible to build a single reactor capable of more than 400MW net output—which means that less plant and fewer stations are needed for the same amount of electricity generated. Though it must be remembered that this progress is a great benefit to the nation, he emphasized, 'as it means a considerable reduction in the capital cost of the plant produced which after all is the aim of industry.' Stations now being built will produce electrical power at costs comparable with conventional stations, but in future stations the cost will be appreciably lower.

On the question of exports of nuclear plant Mr Lindley said that practically every country in the world is interested. Negotiations are in progress for two stations for Germany and one each for Italy, the Netherlands and Belgium and tenders for several complete stations will be submitted within the next six months. This is in addition to the existing Italian agreement for the purchase of a station and the intention of the Japanese to buy a Calder Hall type of reactor (see *Worldview* March). 'But it has to be recognized,' he stressed, 'that many countries, such as Germany, are capable of supplying almost a complete plant themselves and will wish to do so particularly if sterling credit is restricted.' We are seeking to receive an adequate return for giving designs and certain special equipment.

Research costly Mr Lindley's speech was given at the Atomic Energy Division, Erith, where research and development facilities have been recently extended. They aim at improving the gas-cooled graphite-moderated reactor, with particular emphasis on the overseas market. New facilities include a laboratory specially designed for work on beryllium, and in another laboratory the prototype of a remote-controlled power manipulator is undergoing its final tests. In the new mechanical laboratory is a one-twentieth scale model of a Hunterston type power reactor which is being used for gas-flow measurements. 'This research effort is costly,' said Lindley, 'and can only be sustained if the industry is supported by a sufficient flow of work.'



In this GEC model of a Hunterston-type reactor the duralumin core is housed in a Perspex 'pressure vessel' and a blower draws air through to simulate flow of coolant gas

Comprehensive cover

Widespread agreement on the broad approach to insuring nuclear energy risks was reached by representatives of fifteen European countries meeting in London in March. Object of the conference, which was sponsored by the British Insurance Association Atomic Energy Committee, was to discuss cooperation between various European insurance markets in providing cover for reactors now being built—particularly those on the Continent. A reactor would normally be insured by a pool of national interests, but the cover would be spread internationally by means of reinsurance. There was wide agreement at the conference on the management of these pools and also on the types of risks they should cover. Material risks to be pooled should, the conference decided, be the insurance of damage to property belonging to the policy holder. Third party liability for injury to property and to people should also be pooled. It was unanimously agreed that the cover must be comprehensive and not for nuclear risks only and this applies also to third party liabilities. The working details remain to be decided by a special committee which will meet in Paris on April 24: hazards, evaluations and surveys, bases of premium rating and the policy cover to be offered.

Unanimous agreement was obtained for the principle that a single policy should be effected by the reactor owner or operator who should accept responsibility for radiation risks for the contractors and suppliers of parts as well as himself. This channelling of legal liability means that any third party claims will be made solely to the owner or operator. The UK government has already tackled the problem on these lines (see *Worldview*, March).

Enquiries about seventeen reactors are at present being dealt with by the British pool and premiums have been decided for eight of them. No figures are available yet but premiums will be an 'insignificant percentage of the cost per kW,' said A. G. M. Batten, chairman of the British advisory committee. Material damage cover for Calder has been quoted as £M30.

Japan invites tenders

As briefly reported last month in *Companies*, Japan is to have a British gas-cooled power reactor. After their visit to this country in February the leader of the purchasing committee from the Japanese Atomic Power Co, Mr Daigoro Yasukawa, announced that tenders for a 150MW single reactor power station had been invited from the AEI-John Thompson, General Electric and English

Electric groups, the tenders to be submitted by July 31, 1958. Mr Yasukawa told NUCLEAR POWER that the Nuclear Power Plant Co had also been invited to tender but had declined. After extensive studies in England the Japanese company had concluded that the British type of reactor met their three requirements: safety and reliability in operation, safety against earthquakes, economics of power generation. As regards earthquakes, they were satisfied that if the graphite pile is efficiently supported and the pressure vessel and heat exchangers are firmly tied to the shielding concrete structures, an earthquake resistant design can be achieved without impairing reactor economics. Furthermore, the tendering groups have devised special emergency shut down systems especially for this contract.

The power station will be situated at Tokai on the Pacific coast, adjacent to the Japanese nuclear research establishment. From here the output will be fed in to a 275kW grid supplying the Tokio area. It is hoped to start work before the end of the year, and as much as possible of this will be done by Japanese companies working under British supervision.

Her eight-day, eleven-hour underwater crossing of the Atlantic completed, the US nuclear submarine 'Skate' rests in Portland Harbour

Nuclear subs progress . . .

The visit of the American nuclear submarine *Skate* coincided with an Admiralty announcement that work on the UK nuclear *Dreadnought* submarine is now regarded as a matter of urgency. Operating experience with the zero energy reactor NEPTUNE has so far been highly satisfactory, and at the Admiralty's Dounreay experimental site the main building for the reactor and its machinery should be finished by May. Britain has already received a good deal of information on nuclear submarines under last year's agreement with US.

The captain and crew of the *Skate* spoke highly of her reliability and cleanliness compared to diesel submarines after her underwater Atlantic crossing to Portland, it is reported. Average speed of the 2,190 ton craft was 19 knots for the eight day, eleven hour journey. Her five day visit follows that of the larger *Nautilus* atom submarine six months ago, and she is now visiting other European ports before returning to America.

. . . UK merchant ship by 1964?

Britain is going ahead with development of nuclear propulsion for a merchant ship and there might be a ship on the water by 1964, revealed Mr Galbraith, Civil Lord of the Admiralty, recently. A great many nuclear propulsion systems have been examined to see whether any of them could be put straight into a ship without first building a prototype on shore. 'Unfortunately this has turned out to be impossible' he said. 'What we want to do is to build an economic or near economic ship to start. The atomic-powered ships which are supposed to be built in other countries do not even profess to be paying propositions. We believe it is much better to go for what is economic rather than to seek to make a splash of a machine which can have no commercial application.' The AEA has supplied the Admiralty with a lot of useful information and it is now giving priority to 'an advanced feature of atomic technique' which, it is hoped, will pave the way for the development of a smaller unit suitable for ship propulsion. Mr Galbraith emphasized that there is still a lot of hard technical work to be done before anything approaching an economic unit can be produced, but non-starters have been weeded out and work is now proceeding on what is hoped 'will be a winner.'

More power for Scots

The North Scotland Hydro Electric Board is to install a 250 MW nuclear power station in 1966. Location may be north of Aberdeen, but it is hoped to keep transmission lines shorter by siting it between Aberdeen and Dundee. This was announced recently by Mr John Henderson, chief engineer of the South Scotland Electricity Board, speaking for the chairman, Mr J. S. Pickles. The station will probably be completed in 1970 by the addition of a second reactor of the same output. He also indicated that the authorities will face the necessity in 1967-69 of either building a second nuclear station at Hunterston or a coal-burning plant on the Lothian coalfields. The decision will be made on economic grounds.

Hunterston waste It has been suggested that the waste heat from the Hunterston nuclear station might be used for glasshouse purposes, and Mr Henderson has recently outlined the problems which would be involved in this. The station will use 17 million gallons of Clyde sea water an hour for cooling at an average of 42 degrees in winter and 60 in summer, and the cooling process will raise these to 54 and 72 respectively. To secure any useful transfer of heat for glasshouse purposes would require water 10 degrees higher. This could be done by restricting the intake of sea water but only at the expense of a decrease in efficiency of 1·2 pct costing £40,000 per annum. He thought that spoiling efficiency of the station was the wrong thing to do, but more and more electrical engineers are designing with a view to securing efficiency in very small directions, allowing the tail to wag the dog.

Windscale men cleared

There was no intention to reflect on the staff at Windscale in the official report on the accident, says an agreed statement issued after a meeting between Sir Donald Perrott, AEA member for finance and administration, and the secretary of the

Institution of Professional Civil Servants, Mr Stanley Mayne. But the Authority maintains its view that 'errors of judgement were committed on the application of the second nuclear heating.' However these faults of judgement were themselves attributable to weaknesses of organization and as the responsibility was primarily collective the Authority has already accepted full responsibility. The meeting follows Sir Donald's trip to Windscale to investigate complaints arising out of the reports on the accident and the statement added that it was then agreed that some of the points at issue were suitable for reference to Sir Alexander Fleck's technical evaluation committee. Mr Mayne has now submitted a detailed memorandum to the committee and is seeking discussions with them. The Authority emphasized its previous offer that any individual who considered himself to be unfairly criticized in the report could make representations to a

PERROTT
hears complaints

panel of three members and could for this purpose have access to the relevant technical records which were before the Penney Committee of Inquiry.

Changes at Harwell

New Principal for the Harwell Reactor School is Mr James F. Hill, NUCLEAR POWER's consultant physics editor. He was formerly Senior Lecturer at the School and succeeds Dr D. J. Littler, who returns to the Reactor Division.

This follows changes in the courses reported in *Worldview* March. Engineers and physicists will soon attend the first of the six week introductory courses in basic reactor physics at Birmingham, Bradford and Salford technical colleges before going on to the full Harwell course on May 26. Nearly half of the students for the next course will come from overseas.

HILL
now heads Reactor School

BELGIUM

ZETA model at Brussels

Preparations are almost complete for the ceremonial opening of the Brussels Universal and International exhibition on April 17. The UK government nuclear display has been concentrated on aspects of nuclear power which are expected to lead to sales of equipment during the next ten or twenty years, and for this reason the emphasis is on different types of fission reactors rather than on the prospects of evolving a fusion reactor. But to complete the picture a 7ft high model of ZETA, built to a one-third scale of the original, will be shown. Its torus will be made of Perspex so that the interior flash can be seen at 10 sec intervals. The Russians will show a model of an atomic powered icebreaker and the US display will include a continuous diffusion cloud chamber with a 4ft by 4ft sensitive area and an exhibit describing the recent discovery of the free neutrino.

UNITED STATES

Neutrons for tumours

Nearing completion at Brookhaven National Laboratory is America's first big nuclear medical centre with a specially designed reactor for treatment and research. With a floor area of 118,000 sq ft. the new building will have four circular wings with 48 hospital rooms and a large area for research in medical physics, pathology, microbiology, biochemistry, physiology and industrial medicine. To be used solely for medical purposes, the reactor is water cooled and moderated, fuelled with enriched uranium, with an output of 1MW. For experimental treatment of brain tumours, neutron beams can be released from ports in two walls of the reactor, controlled by 19-ton plugs. A patient admitted for treatment will be given an injection of a boron compound and when the boron becomes localized in the tumour, the neutron beam will be directed on it. This bombardment gives rise to short-lived radioactivity which destroys the tumour cells without damaging the normal tissue surrounding them. The treatment room runs to the base of the graphite reflector surrounding the core and provides a thermal neutron flux of from 10^{10} to 10^{11} at the position of the patient's head.

In addition to the experimental neutron-capture treatment, the reactor will produce radioisotopes, including short-lived ones, for studying body processes and treating a wide variety of diseases. Investigations will include fundamental metabolic processes such as transport of body fluids and mechanisms involved in high blood pressure, heart diseases and the development of cancer. Medical research with neutrons has been going on at Brookhaven since 1951 using a general-purpose reactor, but under this system work had to stop when the reactor was needed for other work. In the new centre medical work will be able to go on uninterrupted. Total cost will be about $M6, excluding the outlay for design and engineering. Although the Brookhaven centre is the first specially-designed unit of its type, it will not be the first American hospital to have its own reactor: Bethesda Naval Medical Centre, just outside Washington, has had a reactor working since last November.

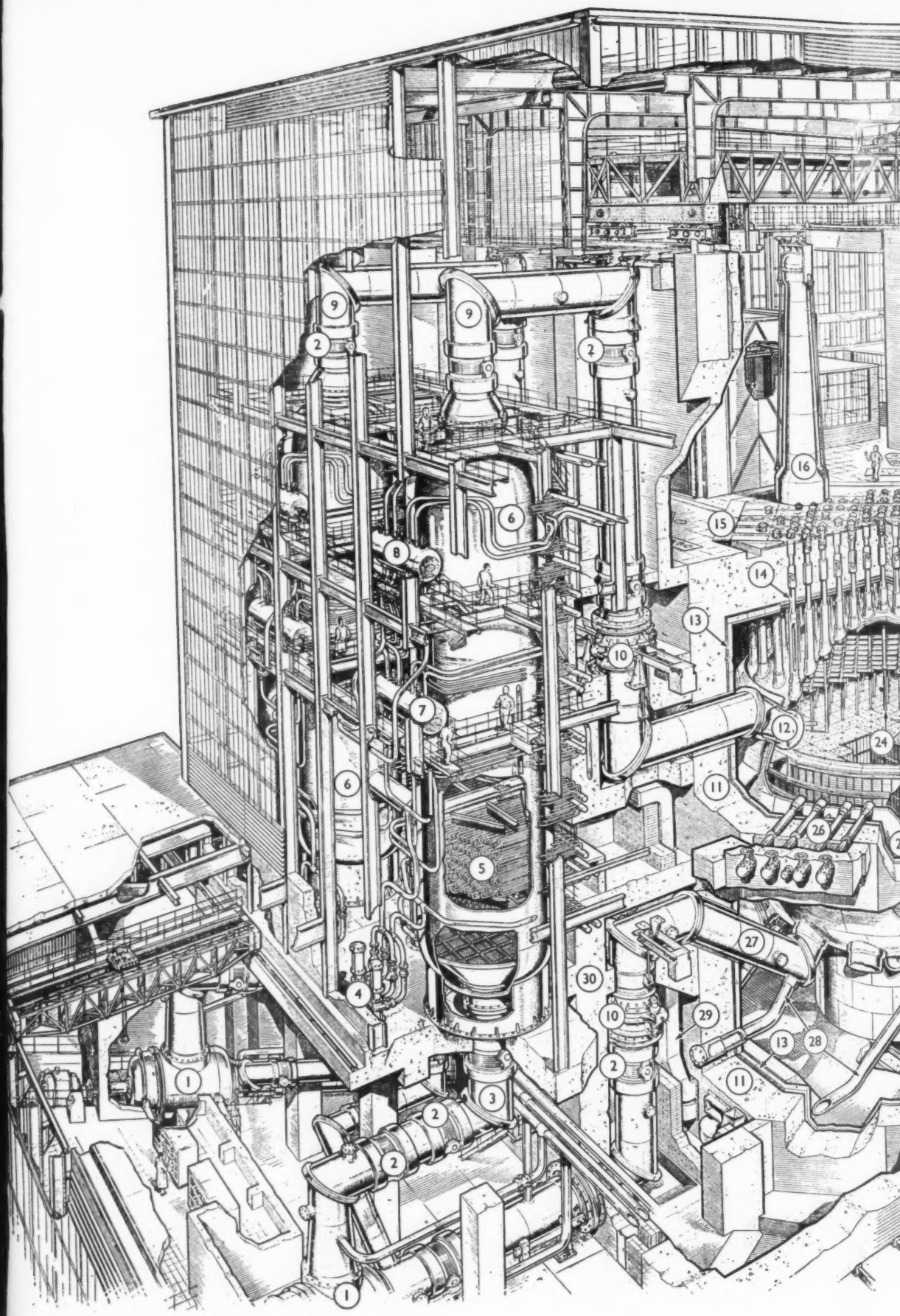
HINKLEY POINT

The latest news about the design of Hinkley Point nuclear power station has just been released by the English Electric/Babcock & Wilcox/Taylor Woodrow Group in the form of this cut-away drawing. No further information was published than is already generally known and covered by NUCLEAR POWER in October when the contract was originally awarded by the CEA.

INTERNATIONAL

US teams with Euratom

The six Euratom nations are to embark on a joint programme of power reactor development with the US, and a working party is to be set up to plan the installation in Europe of 1000 MW of nuclear power plant from American specifications. M Louis Armand, Euratom President, has accepted an invitation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The Central Elec

HINK

Nuclear

under

English Electric/Babcoc

Reactors:	two of ea
Output:	500M
Pressure vessel:	67ft d
Fuel:	natur
Boilers:	six pe 90ft Total hour
Steam:	h.p.:
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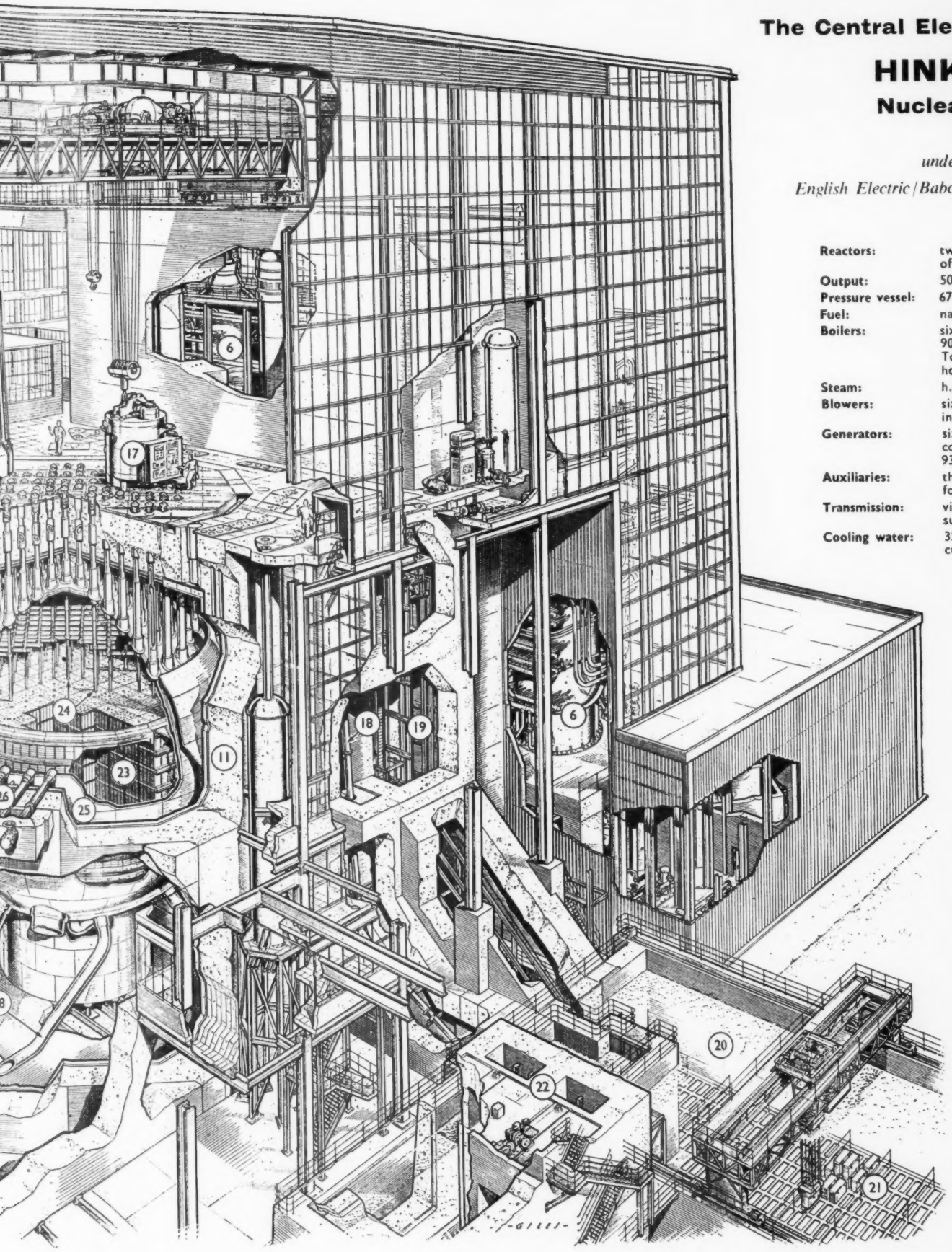
Generators:	six coole 93·5M
Auxiliaries:	three for b
Transmission:	via s super
Cooling water:	35 m culat



The Central Electricity Generating Board

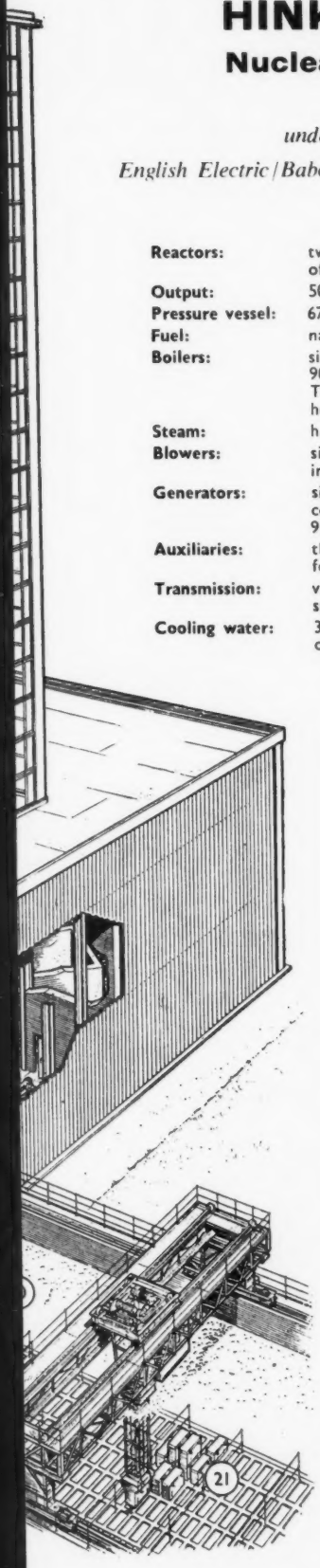
HINKLEY POINT

Nuclear Power Station

under construction by the

English Electric/Babcock & Wilcox/Taylor Woodrow group

Reactors:	two gas-cooled, graphite-moderated; weight of each with pressure vessel, 5500 tons
Output:	500MW guaranteed, 6 x 93·5MW installed
Pressure vessel:	67ft dia sphere, 3in. steel
Fuel:	natural uranium, magnesium-alloy cans
Boilers:	six per reactor, Babcock dual-pressure type, 90ft high, 21ft 6in. dia, weight 1350 tons. Total evaporation 5·5 million lb of steam per hour
Steam:	h.p.: 650 psig, 700°F; l.p.: 200 psig, 680°F
Blowers:	six per reactor, axial flow, variable frequency induction motor
Generators:	six 3000 rpm English Electric, hydrogen-cooled, 3-cylinder turboalternators, each 93·5MW at 13·8kV, 0·85 power factor
Auxiliaries:	three 33MW variable-speed turboalternators for blower drive and other duties
Transmission:	via switching and transformer station into supergrid at 275kV
Cooling water:	35 million gallons of sea-water per hour, circulated by six centrifugal pumps



KEY

1 Carbon dioxide circulators
2 Hinged expansion bellows
3 Carbon dioxide outlet from boiler
4 Boiler circulating pumps
5 Stud-tube elements
6 Boiler (six per reactor)
7 Low-pressure steam drum
8 High-pressure steam drum
9 Carbon dioxide inlet to boiler
10 Carbon dioxide isolating valves
11 Main biological shield
12 Carbon dioxide outlet from reactor
13 Thermal shield
14 Charge tubes
15 Charge floor
16 Hole-preparation machine
17 Charge/discharge machine
18 Emergency discharge chute
19 Spent fuel element skip hoist
20 Cooling pond
21 Storage skips and grid
22 Skip loading bays
23 Graphite core
24 Control rods
25 Pressure vessel
26 Can-failure detection standpipes
27 Carbon dioxide inlet to reactor
28 Debris removal ducts
29 Shield cooling-air ducting
30 Secondary biological shield

to visit America in April for discussions with Mr Dulles and Admiral Strauss, Chairman of the USAEC. In a letter to M Armand, Mr Dulles said that he shared the Community's view that all possible speed is desirable, and the new plan follows talks in Europe between representatives of Euratom, the USAEC, and the Department of State. It will start the US-Euratom cooperation envisaged in the report of the 'Three Wise Men' committee last year on the target for Euratom's power production. The agreement will not rule out purchases of reactors from Britain for some of the remainder of the 15000 MW target for 1967.

Also announced is the appointment of Mr W. Walton Butterworth as US representative to the European Economic Community and Euratom, with the personal rank of Ambassador. He will continue to represent the US at the European coal and steel community—a position which he has held since 1956—and will thus head a combined commission to provide US representation to all three European Communities. He served as Ambassador to Sweden and as Minister and Deputy Chief of Mission at the American Embassy in London prior to his present assignment in Luxemburg.

A representative of Euratom attended a recent meeting of the Steering Committee of the European Nuclear Energy Agency of OEEC which discussed practical means of close collaboration with Euratom. It was agreed in particular that work would be undertaken jointly in the field of public health and safety so that the same basic regulations would be drawn up for all the western European countries.

Britain will not join The question of having British observers at the Euratom Council is now being discussed by Euratom and OEEC, according to Mr Macmillan in the Commons recently, but he said that to join Euratom would pose great difficulties for us, without necessarily increasing the amount of practical cooperation with member countries which is proceeding by bilateral agreements, membership of ENEA, and by the European Council for Nuclear Research.

Geneva will discuss fusion

Scientists and nuclear engineers from the UK are to present about 200 of the 1000 or so papers to be read at the second international Geneva Conference on the peaceful uses of atomic energy next September. 120 will be read by scientists from the AEA and the remainder are from nuclear companies, the Medical Research Council and the Universities.

Highlight of the conference promises to be a series of papers on developments towards thermonuclear fusion, and eight UK papers on this subject will be read. A Harwell spokesman told a NUCLEAR POWER reporter that further progress with ZETA would be revealed. Contrary to widespread press reports that it has been dismantled for extensive modifications and may not be working again until the end of the year, the machine was stripped for a short period for overhaul only, and is now reassembled in working order. However, he confirmed that improvements are to be made, such as reducing the previous one inch gap between the primary transformer windings and the torus, which should increase efficiency and help to give the further rise in temperature required. Russia also intends to report on thermonuclear work, revealed Academician Igor Kurchatov in a recent Pravda article. Soviet scientists, he said, are investigating discharges in doughnut-shaped chambers, but the types used are different from those in the British experiments.

The UK display in the scientific exhibition at the Palais des Nations will total some 5000 square feet, and is being arranged by the AEA. For the Commercial Exhibition at the Palais des Expositions, the AEA has taken a further 3500 feet in the British section. This section is being organized by the Nuclear Energy Trade Association's Conference, which represents nearly all British firms concerned with Atomic Energy, and more than fifty of them will be contributing to the 30,000 square feet display. The Exhibition is being organized by a non-profit making body set up by the Geneva authorities.

The UK delegation, under Sir John Cockcroft, is expected to consist of 5 delegates, about 250 advisers (mainly authors of papers) and 250 observers. The four delegates besides Sir John are expected to be a second representative of the AEA and representatives of the Royal Society, British industry, and the Medical Research Council. The demand for observer passes has been high and anyone interested in attending the Conference as an observer should apply as soon as possible, and in any case not later than April 19.

WORLDBRIEFS

Following successful underground detonation of A-bomb in Nevada talks are in progress between USAEC and industry on possibility of using **atomic explosions** for creating reservoirs in arid areas.

The third reactor of **Calder Hall** became critical recently and has been handed over by the builders to the AEA for commissioning. It will probably be about two months before the reactor starts feeding electricity into the national grid.

After considering five possible sites the East Suffolk Planning Committee yesterday decided to recommend the CEGB to build a **nuclear power station** at Sizewell. A proposal that the electricity authorities should defer the question of a nuclear power station in Suffolk for ten years 'until they obtained more experience' was withdrawn after the chairman, Sir Robert Gooch, had said that the authorities wanted the station to be in operation by 1964.

The projected power station at Thorpe Marsh near Doncaster will use the largest single plant in the world, it is reported. C. A. Parsons & Co Ltd will supply the **550MW turbogenerator** and the boiler will be from International Combustion Ltd.

Four year research and development programme costing over $M5 has been undertaken by Atomics International to determine the electronic feasibility of the Advanced Epithermal Thorium Reactor concept at a full-scale power plant. This operates on the thorium/U-233 cycle—'epithermal' refers to the intermediate speed of the reactions. Coolant is liquid sodium, and moderator, if used, would be beryllium or graphite. Plant would be rated at about 200 eMW.

Complete set of parts for Egyptian research reactor at Cairo has now been delivered from the Soviet Union for assembly by Egyptian engineers under Russian technical supervision. Construction of the reactor building is nearing completion.

US **General Electric's** reactor at Vallecitos Laboratory has been named Vallecitos Boiling Water Reactor (VBWR). Its output was recently stepped up from 20 MW to 30 MW with no design change or addition of fuel. Further increases are planned.

The ACF 30 MW **tank type reactor** for AB Atomenergi of Sweden is now to have 90 pct enrichment instead of 20 pct.

The Martin Co's zero-power reactor went critical recently. Trials in the MTR of the fuel element for Martin's package reactor showed nearly 42 pct burnup in eleven months. Complete structural integrity of the tubular stainless steel element was obtained says the company.

Output of EBWR at Argonne has been lifted to 50 tMW with no change in core. Project manager J. M. Harver said calculations showed this could be doubled with more fuel.

Boron-10 production plant near Niagara Falls, NY, is to be shut down because there is enough stockpiled for several years, says an USAEC announcement.

INSTRUMENTATION 1958

An integral part of atomic energy

Important as it is to all modern industry, instrumentation has always been something more to nuclear energy, and it would not be an exaggeration to say that absolutely nothing could have been achieved without it. In addition to the novel nucleonic instruments which have had to be developed for neutron counting, radiation measurements and health monitoring, the coming of nuclear power stations has demanded the attainment in conventional instruments of accuracy and reliability standards hitherto undreamed of. Both types of instrumentation are now highly developed and this has been largely responsible for the rapid strides now being made towards the goal of economic nuclear power.

This special issue of NUCLEAR POWER has been designed to give an overall picture of the instrumentation requirements of modern nuclear power and research reactor installations and also a review of the latest British instruments available to meet them. It contains five exclusive review articles by the country's leading authorities, in addition to other features of more specialized interest. We have also obtained a special series of messages from prominent personalities in the instrumentation business. Finally we include preview features of two exhibitions starting soon in London—the Physical Society and the second annual Instruments, Electronics and Automation exhibitions.

Here are the highlights of this issue

1 **K. Sandiford,** Chief Instrument Engineer, AEA Industrial Group, Risley, reviews the physical or non-nuclear instruments needed in a modern power station.

2 **B. C. Godbold,** Nuclear Power Sub-department, Central Electricity Generating Board, from the 'user' point of view, indicates lines for development in nuclear power station instrumentation.

3 **W. Abson,** of Harwell and **A. L. Gray,** of Plessey Nucleonics review methods of neutron detection by means of gas ionization devices.

4 **R. B. Owen,** Harwell, does the same with scintillation counting methods.

5 NUCLEAR POWER have had specially prepared a series of diagrams showing the main instrumentation features in (a) a gas-cooled power station (b) a high-flux reactor and (c) a fast breeder reactor.

6 **A. L. Gray,** of Plessey, surveys methods of finding out how the neutron flux varies in power reactors.

7 A special preview of the Physical Society Exhibition (Horticultural Hall, London, March 24-27). If you're going, don't forget to call at NUCLEAR POWER stand 117.

8 A special preview of the 2nd Instruments, Electronics and Automation Exhibition (Olympia, April 16-25).

To Nuclear Power . . .

from **Sir Leonard Owen**, managing director, UKAEA Industrial Group

The importance of instrumentation and control in any undertaking whose processes are based on new scientific discoveries should need no emphasis. Only by instrumentation can an adequate quantitative picture be established from which both safe and economic operation will be achieved. This requirement is paramount in the field of nuclear power for several reasons.

We are using many materials like uranium, zirconium, beryllium and niobium, whose fundamental properties are still being studied in the laboratories. New alloys whose detailed behaviour is still unfamiliar to us will also be employed. We are using both these and conventional materials, like graphite and mild steel, under new conditions—conditions which will steadily grow more stringent as we proceed to the development of reactors with higher thermodynamic efficiencies.

When this is added to the fact that the nuclear power stations are designed in very large economic units, so that a single control room may be supervising an output worth 5 or 10 million pounds per annum, combined with a fission product inventory of hundreds of megacuries, the need for proper instrumentation and control is made abundantly clear.

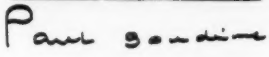
I consider this to be a subject of vital importance to the growing nuclear power industry and express my very good wishes for the success of this issue.

from **Paul Goudime**, president, Scientific Instrument Manufacturers' Association

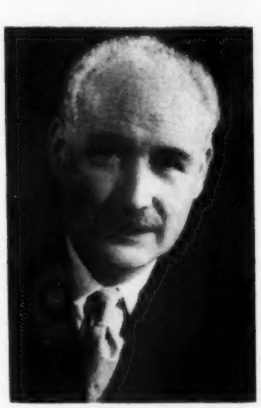
In SIMA there is a nucleonic section composed of some 60 firms, all of which are manufacturers of nucleonic instruments or allied equipment. Many of these firms came into being just after the war when large quantities of Harwell designed instruments were required for the nuclear energy programme. Today most of them have established sound commercial markets and are contributing an important share of original development work on new instrumentation projects.

The European market, which was wide open to Britain after the war, has become increasingly competitive as each country develops its own nucleonic industry to satisfy its national requirements, for, despite the aspirations of the European common plan, the nationalistic instinct in this particular direction is surprisingly strong. Nevertheless, the British nucleonic industry has achieved many notable successes in the industrial and medical fields, not only in Europe but in the United States, where large orders have been and are being secured in the face of intense competition.

While Britain continues to lead in atomic energy there will be ample opportunities for marketing the new and advanced instruments which are being developed and, from the great interest which was aroused by the composite SIMA stand at the Interkama Exhibition in Düsseldorf, it is evident that Europe still looks to this country for the latest in nucleonic instrumentation.



from **L. S. Yoxall**, president, British Industrial Measuring and Control Apparatus Manufacturers' Association

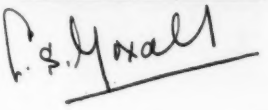


When, in 1956, Calder Hall first fed electricity into the national grid, ten years' work by the British nuclear energy industry culminated in an event of world importance. Today, Britain continues to lead the world in the peaceful uses of atomic energy and the British industrial instrument industry can be proud of the contribution it has made in this new field.

Like many other processes, the production of nuclear power relies heavily on the accuracy and dependability of British industrial instruments. Many new problems arose. Some have been solved by the use of standard equipment in the light of newly acquired specialized application knowledge. Other more difficult problems were solved by close collaboration between the instrument manufacturer, the plant contractors and the power and atomic energy authorities. As a result, a whole range of specialized equipment for use in the nuclear energy industry has been developed. Now the British industrial instrument manufacturer can supply tried and tested equipment, backed by comprehensive after-sales service, in every part of the world.

British industrialists are sometimes accused of being too modest. Perhaps we are, but I do not feel this is the time for modesty. That is why I welcome this issue of NUCLEAR POWER with its preview of the impressive Instruments, Electronics and Automation Exhibition which we are mounting at Olympia in April, and the picture it gives of our contribution to the massive achievements of the British nuclear energy industry.

We have unique knowledge and experience and we should say so.



THE NUCLEAR INDUSTRY

From the earliest post-war period until only about two years ago, knowledge and experience of atomic energy in all its aspects was largely a Government monopoly so that the role of firms was virtually one of a sub-contractor working to the Atomic Energy Authority's requirements. With the launching of the Government's plan for the large-scale development of nuclear power stations however, all this changed and industry was encouraged to go over to the initiative. This opportunity was enthusiastically seized by many firms which now have flourishing nuclear divisions or departments. To find out just how far this process has got in the instrument industry, NUCLEAR POWER has undertaken a special survey, putting to eight typical firms covering the whole field of nucleonic and conventional instrumentation the following question:—

The safe and efficient operation of nuclear energy installations will make increasing and urgent demands on the British instrumentation and control industry. How is your firm meeting this challenge and opportunity?

Here are the replies to that question. They show beyond doubt that Britain's power programme is backed by a vigorous and forward-looking instrument industry.

Heavy and continuing investment in research and development has made Elliott-Automation Ltd capable of bringing the full potential of modern technology into industry. In this, nuclear energy is vital and its instrumentation and control problems have high priority in my plans. My organization's nuclear division, established in 1954, has its own development, production and technical sales facilities so that it can best devote all its thought and actions to these problems. Backed by the whole group, with its wide experience in so many fields, I am confident that this division will make an indispensable contribution to the nuclear power programme.

Leon Bagrit, managing director, Elliott-Automation Ltd

That section of British industry which is concerned with the evolution of equipment and components for the control of complex installations has long faced problems of ultimate reliability and safety where such are vital.

Atomic installations pose many new problems and require much experience from the past. Plessey Nucleonics Ltd has been formed as a quite separate team of engineers, physicists and others for atomic work and has been provided with elaborate scientific and manufacturing facilities. First among the principles which guide their work are those of complete reliability and safety of the product.

A. G. Clark, chairman, Plessey Nucleonics Ltd

Backed by over ten years of experience in the nuclear energy field, my company is meeting the ever-increasing demands for instrumentation brought about by the rapid realization of atomic projects throughout the world.

Valuable know-how has been acquired during these pioneering years and we have already supplied the complete nuclear instrumentation and control circuitry for several research reactors at home and overseas, while Ekco equipment is used in practically every reactor so far constructed. We are continuing to devote our resources to the further development of efficient nuclear instrumentation and hope to continue to play our vital role in this exciting atomic age.

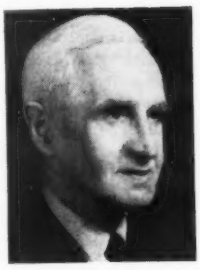
E. K. Cole, chairman, Ekco Electronics Ltd

The principal work carried out by Dowty Nucleonics Ltd is towards reactor safety and simplification. This contribution is through installations using radioactive materials where there is a need for electrical and hydraulic equipment. A team of scientists and engineers are developing equipment for the detection of faulty fuel elements in reactors and this work has progressed to the point where more efficient but far less complex systems are being offered than were hitherto available. Development facilities with live fission products are used so that tests are made simulating any reactor conditions.

Sir George Dowty, chairman, Dowty Nucleonics Ltd

In my opinion an important function of the larger companies and groups with extensive resources for research and development is to provide a systems engineering service. With experts in many fields of technique, such organizations should be able to accept overall technical responsibility, while using specialized products of other firms when they are best suited to the project. A systems engineering group, such as my company is setting up, has facilities for evaluating and testing the latest components and materials. In this way we expect to make our contribution to the high standard of safety and reliability required in this new field.

J. P. Jeffcock, director, Mullard Equipment Ltd



We aim to use our resources to meet the instrument and control needs of this vigorous new industry by combining our experience in other fields, our own research strength, and the specialist knowledge so inspiringly provided by the Atomic Energy Authority.

The Authority's leadership has given this country the initiative in selling nuclear plant abroad. This must be supported by an efficient world-wide technical service. We strive to play our part in this by staffing our overseas companies with technologists of high quality without weakening the quality of our own research work.

Commander P. W. Kent, chairman and managing director, George Kent Ltd

It must be realized that, although there is a large amount of instrumentation associated with nuclear reactors, only a small part of this is concerned with the measurement of ionizing radiation, i.e. nucleonic instruments.

The British manufacturers of nucleonic instruments are able to meet existing demands for this type of equipment quite easily; indeed, the position even now is highly competitive.

It is the view of my company that by far the largest field for nucleonic instruments is associated with the users of the products of reactors, not the reactors themselves, and therefore the emphasis is to develop and manufacture equipment for users of radioactive isotopes, both industrially and for laboratory use.

H. A. Luss, joint managing director, Isotope Developments Ltd

Anticipating the need for extensive instrumentation in nuclear reactors, Sunvic Controls Ltd embarked, some years ago, on a programme of development and expansion. In particular we have evolved a unique system of burst cartridge display for gas-cooled power reactors. The equipment gives immediate warning of significant, as opposed to random, variations in coolant activity and can assess rate of change and average activity, as well as reproduce past recordings. Other developments include a potentiometric recorder incorporating, in one standard instrument, high impedance and other facilities essential for reactor monitoring. Our standard comprehensive instrumentation has been adapted for reactor control desks and panels.

P. G. Oates, commercial manager, Sunvic Controls Ltd

1 PHYSICAL INSTRUMENTATION OF A NUCLEAR POWER STATION

K. R. SANDIFORD, BSc (ENG)
Chief Instrument Engineer, UKAEA, Risley

FOR CONVENIENCE it has become general to consider the instrumentation of a nuclear reactor under two main headings, nuclear and physical. Although this division is convenient in practice, it must be stressed that it is arbitrary, and that the whole instrumentation of a reactor must be designed and installed as an entity. Instruments of each of the two groups have their essential part to play in the start-up, the day to day running and the safety of the reactor. Because of the novel nature of nuclear instrumentation, much work has been done on its development, much discussion has taken place and a great deal has been published on the subject during the past decade. Although it has required a considerable amount of development, physical instrumentation is to a large extent a matter of the application of instruments and methods which have evolved over many years. Many of the instruments required are either available from the range developed for use on chemical plants or can be provided by straightforward modification. Although reference must be made to nuclear instrumentation, as this forms an integral part of the whole installation, the aim in this article is to emphasize the physical instrumentation, and to show how this too is essential to the effective and safe operation of a reactor.

Reactor instruments can be grouped under three main headings:

a. For day to day operation of the reactor

b. For the detection of abnormal conditions

c. For specialized use such as those required for start-up and for use during charging and discharging. In general these instruments will be used only intermittently, and they may be portable, rather than permanently installed.

Instruments in each of the groups (a) and (b) may be arranged to provide warning of abnormal conditions of operation and means for shutting down the reactor automatically in case of an emergency.

CONTROL IN NORMAL OPERATION

Largely because of their small time lags, measurements of neutron flux have proved to be most useful in the control of a nuclear reactor during normal operation: the major part of the heat produced at any instant is proportional to the neutron flux in the core of the reactor. This measurement is convenient for the rapid detection of any change in the rate of operation of a reactor, and also as a guide in adjusting the rate of operation to a desired value. It should be emphasized that, particularly in the case of a reactor for power production, the intensity of the neutron flux has little inherent interest. It is employed merely as a guide in controlling the rate of operation of the reactor to a level which is determined by some other factor.

Because of their relatively high capital cost, it is economical to run nuclear power stations as far as possible at a high load factor, which means that such stations may be expected to run for long periods at full load. In this case it might well be that the limiting factor determining the rate of operation of a reactor is the maximum permissible temperature of the fuel elements. By observation of the neutron flux, the reactor would be adjusted to operate at the highest power at which performance of the fuel elements was satisfactory. In earlier reactors it was necessary to establish this level empirically for each design of reactor and fuel element. The level of operation would be increased by known amounts until the rate of failure of fuel elements became unacceptable, a maximum level for normal operation being established at some rather lower value at which a satisfactory performance of the fuel elements could be expected.

As the characteristics of reactors and fuel elements have become better understood it has become increasingly possible to predict the behaviour of fuel elements under given conditions of operation. The neutron flux in which satisfactory performance may be expected from fuel elements thus becomes a matter of design. In either case, although the measurement of neutron flux is used for the control of the reactor, the level at which the reactor operates is determined by temperature, and the accurate measurement of temperature assumes great importance.

Fuel element temperature

The object of measuring fuel element temperature is to ensure that the temperature of no single element in the reactor exceeds the maximum accepted as safe for whatever design is in use. As there may be 20,000 or more in a reactor it is impracticable to measure the temperature of each. It becomes necessary to compromise, measuring the temperature of some small number of elements with a high degree of probability that the temperature of no single element exceeds the acceptable maximum by more than a known amount. It can be shown by calculation that even in reactors with many thousands of fuel elements, measurement of the temperature of between 200 and 300 will give a probability of 95 pct that the temperature of no element in the reactor will exceed the agreed maximum by more than 10°C. Numbers of measurements of this order are quite practicable.

It is first necessary to decide at which point on the element the temperature should be measured, although in practice it is found that consistency of measurement may

be more important than the precise point chosen for the measurement. A choice has to be made between measurement of the temperature of the uranium or of the can material. If the uranium temperature is to be measured it is necessary to provide a re-entrant tube as part of the can, allowing the temperature sensitive element to be introduced well into the fuel element.

Attaching the thermocouples

In the Calder reactors the elements are about 4 ft long, the cans having circumferential fins, and it was decided to measure the temperature of the can. At a position about 3 ft from the top of the element a fin with a root thicker than normal is provided so that means for the measurement of temperature can be attached. The sensitive element is a thermocouple of T_1/T_2 material enclosed in an outer sheath of stainless steel $\frac{1}{8}$ in. dia and insulated with magnesium oxide. For a length of about 18 in. the end of the thermocouple is swaged down to an o.d. of $\frac{1}{16}$ in. After being passed through a hole drilled in the thickened fin, the reduced end of the thermocouple is flattened and is then pulled back firmly into the hole. The flattened section fixes the thermocouple firmly in the hole by a wedging action, and tests have shown that very good thermal contact is established between the thermocouple and the can. This has proved to be a consistently reliable and simple method of attaching thermocouples without the use of small parts or special equipment.

Thermocouples, mineral insulated and metal sheathed may be used for the great majority of temperature measurements on a reactor. Thermocouple material in this

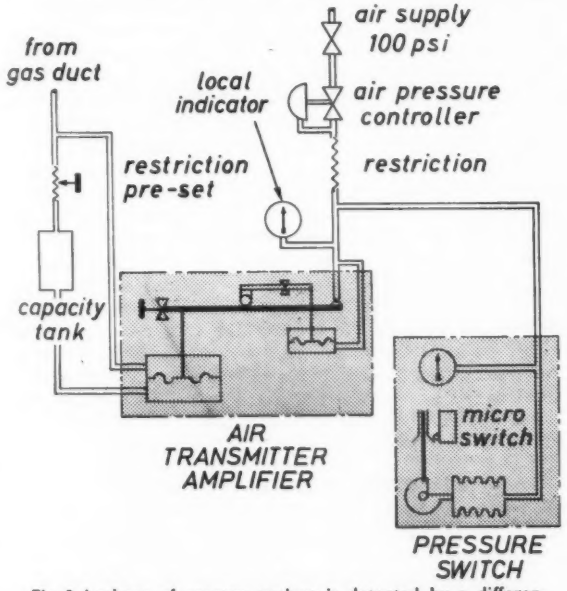


Fig 1 Leakage of reactor coolant is detected by a differential pressure transmitter connected to the coolant circuit. This arrangement measures rate of change of pressure

form is extremely robust and the insulation is unaffected even by prolonged irradiation. Although the hot junction is formed inside the metal outer sheath and is insulated from it, it is desirable, where a number of thermocouples are connected through a selector switch, for both poles of the thermocouples to be switched as a safeguard against errors due to earth faults.

Choice of recording system

In order to detect any fuel element with abnormal temperature conditions, the reading of every thermocouple must be checked in some way at intervals which are short enough to avoid any serious rise in temperature occurring unnoticed during the interval between one reading and the next. It is also desirable to provide means for detecting similarly any unduly rapid rise in temperature. At the same time an unnecessarily large mass of records should be avoided, whether produced by instruments or in the form of log books compiled by process operators.

In the past it has been common to connect the majority of thermocouples to multi-point temperature indicators, the readings of which were logged at fairly long intervals—say once a shift—or even daily, by process operators. From these readings a few thermocouples—say twelve—were selected for connexion to continuously running multi-point recorders. These readings were taken as being representative of the highest temperature among the fuel elements. This method gave a good guide to fuel element temperature provided the operating conditions remained constant, but it was subject to limitations. Any change in the distribution of temperature through the reactor could be detected only at the comparatively long intervals of the manual scan of temperature. The temperature recorders read only the temperature of the fuel elements which had been arbitrarily connected to them. There was no means of detecting an abnormal rate of rise of temperature except in the case of the few thermocouples connected to recorders, and even in this case detection depended upon observation of the record produced on the charts of the instrument. It is not practicable to connect large numbers of thermocouples to multi-point recorders. Although instruments having many measuring points are available, any number of points above eight on one instrument causes serious intermingling of the records on the chart. It becomes extremely difficult to identify individual records, and it is doubtful whether the trend of any record can be determined with certainty. Even with eight-point recorders the number of instruments required becomes very large. Large numbers of charts require changing and so many records are produced that interpretation of them becomes very difficult.

Typical conditions

Whatever may be the method of presenting information from all the fuel element thermocouples, the following are typical of the conditions which should be met, depending upon the design of the individual reactor. The equipment should:

1. scan all thermocouples successively at intervals sufficiently short to avoid the possibility of any temperature rising to a dangerous extent between one reading and the next of any point; the interval may be ten minutes or less
2. detect any point of which the temperature exceeds a predetermined maximum value
3. detect any point of which the temperature is rising at a rate exceeding a predetermined maximum
4. give warning, audibly or otherwise, of any point specified in 2 or 3 above and print out automatically the point number and value
5. select automatically at fixed intervals the points having the highest readings and connect them to continuously running recording instruments so as to provide continuous visible records of these points
6. print out at fixed intervals, or on demand, the readings of all points
7. record all readings over a limited period by some means such as punched paper tape or magnetic recording tape, so as to provide a complete record during the period of any such test.

Data logging and processing

Although these conditions cannot be met by conventional recording instruments they come within the capacity of modern data logging and processing equipment. Work is now proceeding on equipment which will scan all thermocouples at high speed, comparing the readings of each in turn with a pre-set value.

Nothing occurs so long as no reading exceeds this pre-

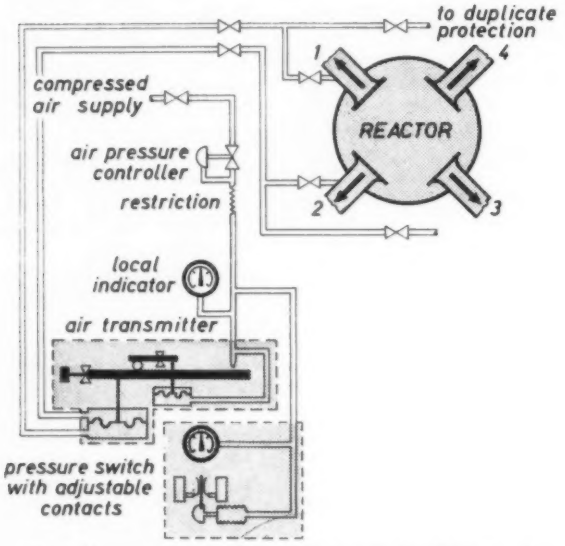


Fig 2 If a coolant circulator fails it may be driven in the reverse direction by the pressure generated by the ones remaining. This is prevented by detecting any variation in coolant flow with a differential pressure transmitter

set value. Any reading exceeding this value causes an alarm to be given and the point number and the value of the reading to be printed. As the scan proceeds, each reading in turn is compared with the stored value of the previous reading of the same point to determine the rise in the value during the known period of the scan, and hence the rate of rise of the value. Warning is given if this exceeds a pre-set rate, with corresponding printing of the point number and rate of rise.

For such equipment it is desirable to use either a mercury jet-type switch or a number of mercury wetted relays to scan the thermocouples in order to avoid trouble from spurious contact potentials in the scanning system. Some form of analogue to digital conversion of the readings is required and successive readings; also the alarm settings are stored either in a magnetic drum or in matrices of ferrite cores. It appears likely that equipment of this type will be used increasingly for the display of information wherever it is required to detect occasional departures from the normal among large numbers of measurements. Other possible applications in addition to the fuel element temperatures already mentioned are temperatures of the graphite moderator and the readings of the burst slug detection equipment.

Coolant flow meters

Although the instruments for the measurement of neutron flux and of temperature can be considered to be the main instruments for the control of the reactor, many other subsidiary instruments are required. In general these are not used directly in the control of the reactor, but they are none the less essential to its satisfactory operation.

Associated with the coolant circuit it it is usual to find meters for measurement of coolant flow in each branch of the circuit. These serve as a check on the satisfactory operation of the coolant circulation, and they are also used occasionally in establishing the heat balance of the system. In normal operation they are needed in balancing the flow of coolant in the various branches of the circuit. Care is required in the design of any device required in the coolant circuit for the production of a differential pressure to operate a flowmeter. In a reactor for power production a large amount of power is required to drive the coolant circulators. In order that this power may be as small as possible it is necessary to keep to a minimum the pressure drop around the coolant circuit, and it is therefore necessary to consider most carefully any device in the coolant circuit which increases the pressure drop in the circuit.

Transmitting type flowmeters would normally be fitted, the readings relating to all branches of the coolant circuit being displayed in the reactor control room. For normal operation indicating instruments are sufficient, but it is necessary to fit recording instruments if it is required to produce records of the rate of flow over a period so that the total flow during the period may be obtained.

Heat exchanger instruments

Associated with a reactor for power production are the heat exchangers which take the place of the boiler in a conventional power plant. The heat exchangers each require the instruments found on a normal boiler in connexion with the feed water and steam systems. These include instruments to check the condition of the feed water, and its rate of flow. On the heat exchangers are water level indicators, steam flowmeters being provided to measure the flow of steam from the heat exchanger. Where steam is generated at more than one pressure, as at Calder Hall, separate flowmeters are required for the high pressure and for the low pressure systems. In any case where the design of the plant provides for wide variations of steam pressure, it is necessary to compensate the readings of the steam meter in accordance with the variation of pressure. This can be arranged automatically by the application of a pressure sensitive element operating in conjunction with the flowmeter.

Instruments for all these measurements follow normal boiler house practice. In many cases transmitting types of meter are required, the presentation of the records being either on local instrument panels or in the central control room according to the system of plant control adopted. If local panels are provided adjacent to the heat exchangers, it may be desirable for the reading of some of the instruments to be repeated in the central control room.

DETECTING ABNORMAL CONDITIONS

In addition to the nuclear instrumentation, provision is commonly made for detecting the following abnormal conditions in the reactor:

1. excess pressure in the coolant circuit
2. leakage of coolant
3. failure of coolant circulator
4. leakage of coolant into the steam system
5. leakage of steam into the coolant system

1. Excess pressure in the coolant circuit

In addition to a safety valve for the relief of excess pressure, a pressure-operated switch connected into the general alarm circuit of the reactor gives warning of any undue rise of the coolant pressure.

2. Leakage of coolant

Under cool conditions the pressure of the coolant gas is considerably less than at normal operating temperature.

The coolant circuit is charged to a reduced pressure such that, as the system is heated, the gas pressure increases until it reaches the desired operating pressure. Because of this variation of pressure during normal start-up, it is not possible to detect loss of coolant, and hence a leakage from the coolant system, merely by detecting a drop in pressure from a normal value.

Leakage is detected by means of equipment sensitive to

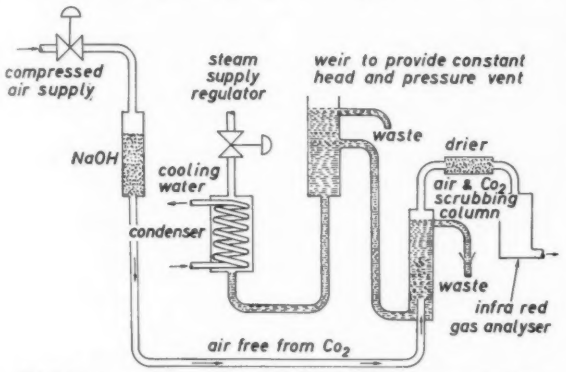


Fig 3 The steam system is sampled continuously to test for coolant leakage into it. Coolant remains in the condensed sample and is removed by carbon dioxide-free air stream

rate of change of pressure and comprising a differential pressure transmitter connected to the coolant circuit. One side of the transmitter is connected directly, the other side being connected through a fixed capacity tank and a variable restriction as shown in fig 1. Under steady conditions, the steady pressure of the coolant is applied to both sides of the pressure transmitter. If the coolant pressure falls, the reduced pressure is applied very rapidly through the direct connexion, while on the other side of the transmitter a lag is introduced by the capacity and restriction. A differential pressure is thus applied to the pressure transmitter, the value of which is determined by the rate of change of coolant pressure and the adjustment of the variable restriction. The arrangement is sensitive to a change of pressure, up or down, from whatever may be the absolute value of the pressure at the time. The air pressure output of the pressure transmitter is connected to a pressure operated switch, the whole equipment being adjustable over the range 1 to 10 psi/min.

3. Failure of coolant circulator

Failure of one circulator in a coolant system with more than one branch can mean that the faulty circulator may be driven in the reverse direction by the pressure generated by the ones remaining. In some circumstances this is undesirable and equipment is provided to detect any appreciable variation in the flow of coolant in any one branch of a multi-branch circuit.

The arrangement of the equipment is shown in fig 2. In each branch of the circuit, some means of producing a differential pressure dependent upon the flow of coolant in the branch is introduced. The means employed may be an orifice plate or similar device introduced for the purpose, or it may be possible to use a restriction in the circuit already existing through some feature in the mechanical design of the coolant circuit. A similar reduced pressure is produced by the restriction in each branch under normal balanced conditions of flow. Connexions are taken in pairs from the low pressure points of the branches in turn to a number of differential pressure transmitters. During normal operation with equal flow in each branch, each of the pressure transmitters has equal pressures applied to its two sides. If the flow in any one branch decreases, the pressure from the low pressure tapping point in that branch will rise and will be detected by one or more of the differential pressure transmitters. Detection is dependent upon the variation of the flow in one branch from the flows in the remaining branches and is not dependent upon departure from any arbitrarily set value. As in the case of the coolant leakage detector, the output air pressure of each pressure transmitter is connected to a pressure operated switch, the combination of pressure transmitter and pressure switch being adjustable to give any desired degree of sensitivity.

4. Coolant leakage into the steam system

This can occur in a system in which the pressure of the coolant exceeds the steam pressure at some point where the coolant and steam systems are in contact. Unless detected and corrected it can lead to corrosion of the coolant system.

The arrangement of the equipment is shown in fig 3. A sample of steam is continuously taken from the system and condensed. Any carbon dioxide coolant which may have leaked into the steam remains in the condensate from which it is extracted by a stream of air free of carbon dioxide which is bubbled through the condensate. The air, after drying, is passed through the measuring tube of an infra-red gas analyser, the reference tube of which contains dry air free of carbon dioxide. Carbon dioxide detected in the analyser is a measure of the amount which has leaked into the steam system. The equipment is sensitive to 0·1 cc. of carbon dioxide per litre of water.

5. Leakage of steam into the coolant system

This is a more general fault as the steam pressure would in most cases exceed the coolant pressure. The arrangement of the equipment is shown in fig 4. A continuous sample of gas is taken from the coolant system and after cooling is passed through the measuring tube of an infra-

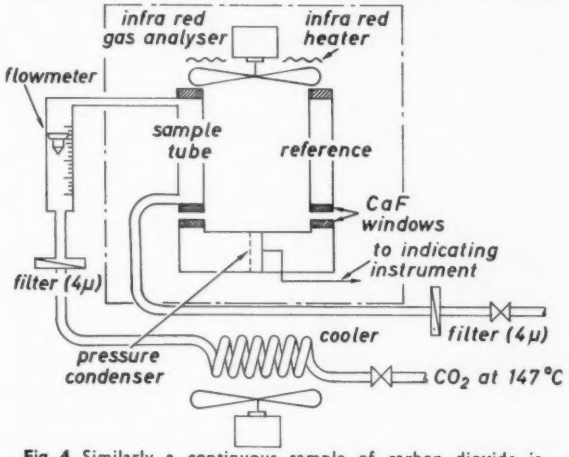


Fig 4 Similarly a continuous sample of carbon dioxide is taken from the coolant circuit to detect any leakage from the steam system. Sensitive instrument is an infra-red analyser

red gas analyser. The reference tube of the instrument is filled with dry carbon dioxide. Steam which may have leaked into the coolant circuit remains as water vapour in the cooled gas and is detected in the analyser. The equipment is calibrated to detect 0–140 ppm by volume.

Alarm circuits

In order to ensure safe and reliable operation of a reactor, it is not sufficient merely to provide instruments capable of detecting abnormal conditions. If such instruments are dependent upon the attention of a process oper-

ator there is always the danger of his missing an indication of abnormal conditions. This may lead to an emergency shut down of the plant which, with proper attention, could have been avoided, or in extreme cases to damage to the reactor.

It is convenient to arrange relay circuits, initiated by contacts on appropriate primary elements, so that audible warning is given when an abnormal condition occurs. At

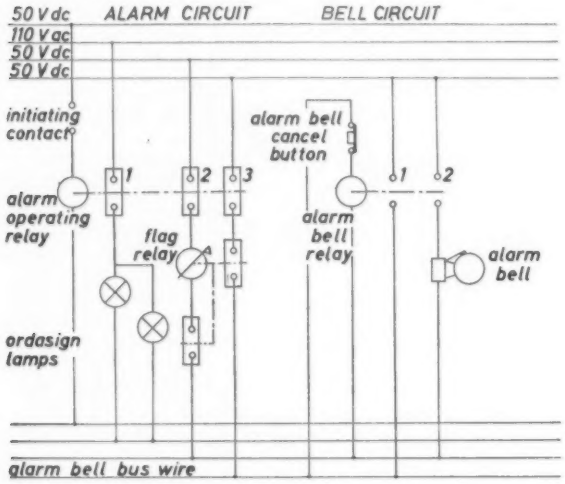


Fig 5 This arrangement of a typical alarm circuit shows how both audible and usual alarms are provided. The latter are ordasigns, or illuminated annunciator panels

the same time an appropriate glass panel is illuminated carrying wording which serves to identify the fault causing the alarm. In order to avoid the distraction of a prolonged noise in the control room it is usual to provide means to stop the audible warning even before a fault has been cleared, although the appropriate glass panel would remain illuminated until the clearance of the fault. Two lamps are normally fitted behind each alarm window so as to avoid loss of indication through lamp failure. It is convenient to reduce the number of alarm windows which would be necessary by providing windows each covering a group of alarm conditions and providing in addition a number of flag relays to identify the individual alarms with the main group of alarms.

Fig 5 shows the arrangement of a typical section of an alarm circuit. As many sets initiating contacts and alarm windows as may be necessary can be added to any one alarm system.

Safety circuits

Certain abnormal conditions in the operation of a reactor are sufficiently important to justify the automatic shutting down of the reactor. Although such conditions vary with the design of an individual reactor, they may include the following:

1. excess neutron flux
2. excess temperature of various parts of the system
3. complete or partial loss of flow of coolant
4. leakage of coolant.

One or more primary devices are required to monitor each of the conditions for which provision is to be made in the protection system. Electrical contacts on each of these devices are arranged in a circuit designed to operate the shut-down equipment of the reactor under pre-arranged conditions. At present it is usual for such protective circuits to be based upon the use of electro-mechanical relays. Although circuits of this type have proved highly satisfactory, the alternative use of solid state switching devices may offer some advantages. The possible application of such devices to reactor safety circuits is being investigated.

In either case, these basic requirements must be met:

1. the reactor must be completely protected against damage resulting from an abnormal condition of operation
2. shutting down of the reactor unnecessarily through faulty operation of the protective equipment must be avoided as far as possible
3. failure of any part of the protective equipment should not result in a dangerous condition
4. failure of any electrical supply associated with the safety circuit should not result in any reduction of the degree of protection
5. provision should be made for the testing of the protective system without interfering with the operation of the reactor
6. provision should be made for the operation of the reactor, if necessary with an agreed number of the safety devices inoperative. Proper means must be provided for putting out of action any such parts of the system, and direct indication should be given of any parts of the system so affected
7. the components of the safety circuits should be enclosed in a locked compartment, or otherwise protected from unauthorized access
8. the physical layout of the safety circuits should be such as to prevent accidental reconnexion of leads in any but the correct manner, for example after disconnexion for testing
9. a safety circuit will often include a number of sets of relay contacts in series. In such cases the components of the circuit should be so arranged as to avoid any accidental connexion between the ends of the circuit which would have the effect of short-circuiting a number of the intermediate sets of relay contacts.

Component selection and layout

In order to meet these conditions, considerable care is required in the selection of the components of a reactor safety system and in the layout of the safety circuits. Where relays are used, consideration must be given to the need for cleaning the contacts, although by suitable enclosure, the need for such cleaning should be minimized. Contact materials should be chosen allowing for the fact that the relays of a reactor safety system, unlike those of a telephone system, are likely to operate only very occasionally. In certain cases it may be desirable to incoporate some plug-in arrangement in mounting the relays to facilitate maintenance. Apart from this, all connexions in a reactor safety circuit should, as far as possible, be permanent to reduce the chance of circuit failure. The need to avoid spurious operation of the protective equipment may require the duplication of some parts of the safety circuit, and the connexion of some units in coincidence. By this means it can be arranged that an agreed number out of a group of protective devices must operate together in order to shut down the reactor. The arrangement most commonly used requires the operation of two out of a group of those devices, but other arrangements are possible, and may be desirable in some cases.

From the foregoing it is apparent that all the principles of good instrumentation practice are applicable to the physical instrumentation of a reactor. As in any other branch of plant design, economy of first cost must be balanced with an appropriate degree of accuracy and reliability in operation, and economical maintenance must be provided.

2 INSTRUMENTATION TRENDS IN NUCLEAR POWER STATIONS

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THE GRAPHITE MODERATED, gas-cooled reactors of stations now being constructed for the electricity supply authorities of Great Britain do not differ fundamentally from Calder Hall, the instrumentation and control equipment of which have already been described (*1, 2, 3, 4, 5*).

It is not appropriate in a review article to give detailed descriptions of equipment, nor is it practicable to discuss the whole field of instrumentation in a short article and certain items only have therefore been selected for comment. In particular no attempt whatsoever has been made to deal with radiation monitoring or other instrumentation required for the protection of personnel.

This article attempts to indicate the lines along which development efforts on nuclear power station instrumentation should be directed in the immediate future, and to give some indication of the technical importance and the financial value of the various classes of instrumentation concerned, so that efforts to reduce the capital cost of future stations may be viewed in the correct perspective.

Single control room

One departure from the practice at Calder Hall which is worth noticing is the provision at CEGB stations of a single control room for the whole power station from which the reactors, boilers, turbines and alternators may be controlled under running conditions. In this way an overall picture of the operation of the station is obtained giving satisfactory coordination of control with reasonable economy in staffing. At the same time careful consideration must be given to the layout and presentation of information if the engineer-in-charge and the operators are to obtain the maximum possible benefit from this centralization of information. Only indications and records which are needed for immediate operation, under all forseeable conditions of the station, should be immediately under the eye of the operators, and recorders should be used here only when a knowledge of the trend is necessary if a correct decision is to be taken.

The minimum possible amount of equipment requiring maintenance should be installed in the control room, a suitable apparatus room being provided immediately adjacent to house such equipment, together with the safety and nucleonic apparatus. In this way it is hoped to reduce as far as possible the mutual interference between the instrument maintenance staff and the staff operating the station, and at the same time to enhance the reliability of the equipment by reducing the hazard from dust, which is inevitable in a room in constant use. It is hoped that it will be possible to pursue this policy still further in later stations as suitable equipment becomes more readily available.

Some of the special problems which arise when considering the instrumentation of nuclear power stations do so because much greater importance must be paid to the correct functioning of the instrumentation than in conventional stations, and in consequence very high availability and reliability of instrumentation must be achieved.

Particular attention must therefore be given to the provision of facilities for the adequate maintenance of the equipment, possibly with the reactor on load, without seriously restricting the performance of the reactor and its associated safety equipment.

Other special considerations arise from possible incompatibility of materials when used in a reactor, from the possibility of radiation damage in certain applications such as the discoloration of glass in TV equipment, the loss of electrical insulation of materials under irradiation, embrittlement of polythene, and so on.

Conventional plant

The techniques used for the instrumentation connected with the conventional plant, for example the turbines and alternators, do not differ markedly from those used in stations burning traditional fuels. In the case of the boilers however, the control is now centred in the station control room and telemetering, remote level indications, etc, have therefore had to be provided. Staff are thus removed from the immediate vicinity of the boilers, which are sources of radiation, and this change helps to reduce the integrated radiation dose which personnel receive.

Certain of the physical measurements, e.g. coolant flows, are connected into the safety circuits. This usually means triplication of the measurement and care must be taken to ensure that testing or other work on one of the originating elements cannot affect the other elements, through pressure surges in a common manifold or in other ways.

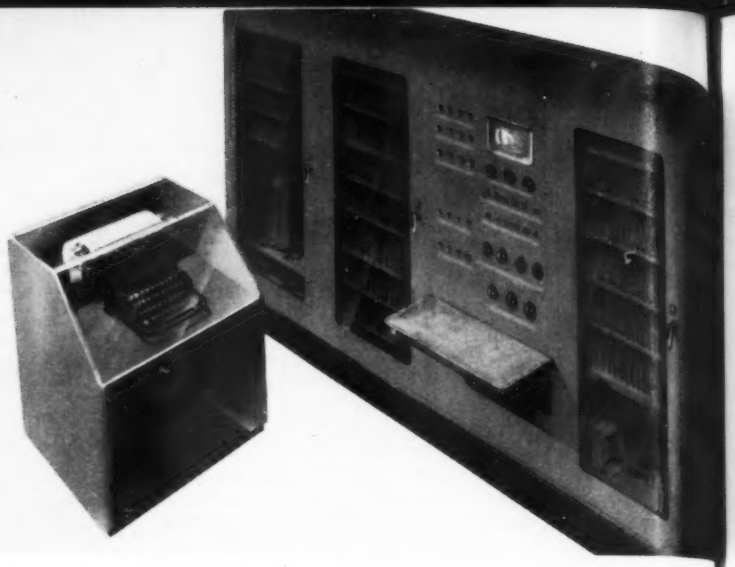
Reactor conditions

At low power levels in the reactor temperature measurements do not provide an adequate indication of reactor conditions and the most satisfactory indication is given by measurements of the rate of fissions taking place. Measurements of the reactor period are made and facilities provided to trip the reactor through the safety circuits if this period becomes unduly short. Similarly shutdown amplifiers are provided to trip the reactor when operating at high powers if the fission rate exceeds a preset maximum.

The actual neutron detectors are located, as at Calder Hall (*1*), in a thermal column placed alongside the reactor vessel and within the biological shield. Neutrons escaping from the reactor are thermalized in this column and a convenient level of neutron flux is obtained for operating

BURST SLUG DATA PROCESSING
the two approaches

Eight multipoint chart recorders or one computer?



neutron detectors. Neutron sources are placed in the reactor and have the effect of raising the fission rate when the reactor is shut down. However separate instruments must be provided for neutron flux indications at low and high powers in view of the range of neutron flux to be indicated, the low power detectors being withdrawn from the thermal column into the biological shield when the reactor is operating at power in order to avoid radiation damage and to maintain accuracy of indication when operating at low powers.

Safety circuitry

Circulator supply failure alarms, certain of the 'physical' measurements on the reactor and some of the neutron flux measurements are interconnected by the safety circuits with the object of ensuring that no combination of circumstances can arise which will jeopardize the safety of the reactor, its operators or the environment, without the reactor being shut down automatically and in time to prevent damage from transient conditions which may occur during such a shut down.

The precise method of interconnexion adopted varies according to the reliability which can be expected from the measurement concerned, but in general there are three 'safety lines'. Any measurement connected to the safety circuits is made by three separate and distinct elements, on each of which there is a contact, one of these contacts being connected in each safety line. The safety circuits are so connected that if one line only is affected then an alarm is given, but if two or more lines are affected then the control rods are dropped into the reactor and the reactor shuts down. These are the 'two out of three' circuits to which reference is often made. The safety lines are always arranged to fail safe, that is the alarm condition opens the contact so that a dirty contact or failure of the electric supply to the circuits gives rise to the alarm condition or reactor trip condition, depending upon whether one or more lines are affected.

The burst slug detection equipment at these stations is fundamentally the same as at Calder Hall (*3, 4, 5*) although various detail rearrangements and improvements have been made to the equipment.

At Berkeley a computer system (*6*) is being provided for the interpretation of the channel activities as measured, but it has been thought prudent to operate a recorder display system similar to that at Calder Hall in addition, to assist in the interpretation of results until such time as operating experience has been obtained and the alarm conditions on the computer can be set up with confidence.

The provision of the centralized control room has inevitably increased the distance over which information must be telemetered, which has the effect, if pneumatic equipment is used, of increasing the time of response of the equipment and the possibility of leakage of the pipes. The air compressors require maintenance attention and difficulties may arise due to oil vapour. Finally if the measurements must be connected to the safety circuits, the failure of the air supply would trip the reactor and so constitutes an additional possible source of incorrect tripping since the electrical supply to the safety circuits must be provided anyway. Electrical transmission of information is therefore preferred although pneumatic telemetering still persists in one or two isolated instances at the present time.

Economics of instrumentation

Unfortunately, no detailed cost analysis of the stations now under construction is available for publication. An approximate estimate of the cost of the instrumentation of a typical nuclear power station has, therefore, been prepared and is given in the table but it must be understood that individual designs may well show substantial departures from the figures given. The figures should be considered in relation to the contract value of these two-reactor stations, stated in the press to be approximately £M40.

In view of the high capital cost and low fuel running costs of nuclear stations compared with conventional stations, a very high availability and load factor must be achieved if nuclear power stations are to be economically

Estimated instrumentation costs for typical gas-cooled reactor

Boiler and steam instrumentation ...	£20,000
Physical measurements associated with reactor gas circuit, reactor temperatures, etc.	£60,000
Control rod position indicators ...	£20,000
Nucleonic and reactor flux measuring equipment	£25,000
Safety circuits and associated special equipment	£12,000
B.s.d. instruments and precipitators	£75,000
B.s.d. pipework and valves—cost is very dependent on layout and design adopted	£150,000 (say)
Miscellaneous equipment e.g. TV, flux scanning, and special equipment for commissioning the reactor	£40,000 (say)
Turbine instrumentation (as for conventional stations)	—
	£402,000

No allowance has been made in these estimates for the cost of data processing equipment where this is to be provided.

satisfactory. The availability and reliability of a nuclear station are vitally, although by no means solely, dependent upon the performance of its instrumentation. It may be worth noting that the cost of running alternative plant has been calculated as being between £10,000 and £15,000 per day, should a nuclear reactor not be available at the time of winter peak loading, depending on the size of the reactor amongst other factors and making allowance only for the actual difference in running costs.

The need for the instrumentation to trip the reactor correctly if and when necessary and yet to discriminate against incorrect tripping has already been stressed. The cost of the actual instruments on which reliable performance of the reactor so largely depends, and in particular the cost of the nucleonic instrumentation, forms only a minute percentage of the total cost of the station.

There is no justification, particularly at this early stage in the programme, for attempts to economize on the cost of the instruments in these stations with the consequent possibility of a reduction in their reliability and restriction of future development.

Questions are often asked regarding the application in nuclear power stations of data logging and data processing equipment. Insofar as conventional plant is concerned such applications are largely a question of economics, the balance between the saving of man hours of a meter reader, who may well have to be on site anyway for other duties, against the capital cost and the maintenance charges incurred. Engineering judgment must be exercised when considering such a proposal in assessing the increased reliance which may be placed upon the information so obtained, offset by the fact that the human meter reader may detect that an instrument is performing abnormally and so report an instrument fault that might escape detection over a period when using data logging equipment.

Use of data processing

In a large nuclear power station, however, the amount of information which has to be presented to the control engineer, if he is to obtain a true picture of reactor performance, is so great that some form of data processing may well be justified on this score alone.

Furthermore, it may be that suitable data processing equipment can analyse a relatively small number of measurements, where a larger number cannot be made, and present a more complete analysis of the conditions of the plant than would be possible by visual examination alone of the individual records. Again, the equipment may give an indication or alarm of an excessive rate of change which would be of considerable value operationally but difficult to obtain otherwise.

Reliability essential

It is quite clear, however, that if data processing equipment is to be considered for such an application very careful attention will have to be paid to its design to ensure that, under all possible operating conditions, satisfactory reliability of operation is obtained, expressed in terms of the number of faults occurring over a long period rather than the number of failures per unit of data handled. Conservative design ratings, inbuilt marginal testing facilities, an inbuilt and automatic self checking system and the fact that the equipment will not normally be switched on and off may all help in this respect.

Burst slug detection equipment is clearly a field in which data processing will find immediate application. At Calder Hall there are 1696 fuel channels per reactor which are normally monitored in groups of 4 and the group activity displayed on 54 point recorders, the record of each group activity measuring 1 in. by 1¾ in. There are thus 424 small graphs displayed on 8 recorders which must be examined periodically for changes in activity.

In the reactors for the electricity authorities there are approximately twice as many fuel channels as at Calder Hall so that the need for some form of data processing and alarm system becomes apparent, assuming that the same form of b.s.d. monitoring equipment continues to be used and its sensitivity is to be maintained.

There are clearly other fields where data processing could be applied with advantage if suitable equipment can be obtained at an economic price and having satisfactory reliability, particularly as in these fields incorrect information may be much more dangerous than the limited information which can be measured and displayed using conventional apparatus.

There is obviously a need for careful consideration in deciding how much of the information available from such a data processing equipment is required to be available in the form of permanent records.

Future nucleonic developments

The paragraphs which follow are not intended in any way to indicate that progress and new developments are undesirable but it is felt that there is a need to some extent to consolidate existing techniques for power station use and in particular to examine the fault liability of equipment (7). Nucleonic instrumentation in nuclear power stations will, doubtless, continue to play a vital role and it seems justifiable, therefore, to re-design equipment, where requisite, to suit the conditions existing in power stations rather than to adopt equipment which was designed for the often less onerous conditions of service and maintenance existing in laboratories.

Reliability in operation cannot be too highly stressed and in this connexion there may be reason to doubt the wisdom of using miniaturized components for electronic equipment in power stations.

There are, of course, good and sufficient technical reasons why small components should be used in certain radio and radar equipments but if the incorporation of such components in power station nucleonic equipment results in decreased reliability of operation then this is too high a price to pay for the saving of space and the easier mechanical handling of a unit, which are generally the only advantages resulting from miniaturization applied to power station instrumentation. Again, in the design of such equipment attention must be given to the elimination, wherever practicable, of close tolerance components and the design must ensure really adequate margins of operation about the nominal operating conditions in order to ensure that all equipment will continue to function correctly under any practicable combination of adverse circumstances.

Acknowledgments

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3 GAS IONIZATION NEUTRON DETECTORS

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THE DETECTION and measurement of neutrons is of fundamental importance in experimental nuclear physics, in reactor physics and in the operation and control of nuclear reactors. A very large variety of detectors have been developed, but the purpose of this article is to review the design and operation of the main types of neutron detector which operate on the principle of gas ionization.

Since neutrons themselves do not produce ionization, their detection must be accomplished by means of the ionizing products of neutron induced reactions. The reactions which are principally used are the elastic scattering processes by fast neutrons, and the n-α and n fission reactions. The recoil protons produced by elastic collisions between fast neutrons and hydrogen nuclei can produce ionization and may then be detected. Thermal neutrons, that is, neutrons in equilibrium with their surroundings, have insufficient energy for detection by this means, but will produce an n-α reaction in B-10, yielding a lithium nucleus and an alpha particle, with an energy of 2·4 MeV. This reaction has a large cross section and since boron may be obtained in convenient physical forms it is much used in neutron detectors. Slow neutrons may also be detected by the fission reaction with U-235 which yields heavily ionizing fission fragments with a mean energy per fission of some 160 MeV. Again this reaction has a large cross section and is a convenient one to use. Other fission reactions such as that with U-238 or Th-232 may be used for the detection of fast neutrons of appropriate energies.

The energy of the charged particles produced in the neutron reaction is absorbed more or less completely in the gas with which the counter is filled, producing an ionized track. The ionization may be collected by applying an electric field between the electrodes of the detector and in a continuous flux of neutrons this flow of charge may be measured either as a mean current or alternatively as a succession of discrete events, each one corresponding to the release of ionizing particles from a neutron-induced reaction. Detectors intended for operation in the former manner are usually known as d.c. ionization chambers, those operating in the latter manner as pulse counters. Mean current detectors are inherently sensitive to any ionizing radiation and will respond to external gamma radiation or to beta and gamma radiation from neutron-induced activities in the materials of the chamber. Of these, the most serious are the effects of incident gamma radiation since the gamma background in which measurements are to be made is not necessarily known. Residual activity effects are directly related to the neutron irradiation history of the detector. If the gamma background is known or may be measured independently, the range of application of mean current detectors is very wide and their use, particularly in the field of reactor control, has been extensive.

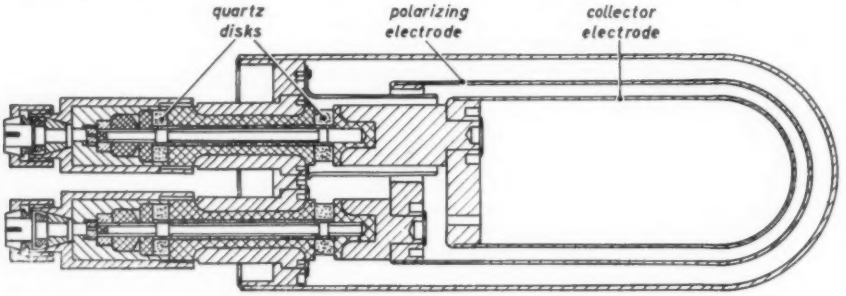

Fig 1 Widely used for detection of slow neutrons, the AERE type RC 1 d.c. ionization chamber

Pulse counters, in contrast to d.c. ionization chambers, provide inherent discrimination between different types of ionizing events. The counters are of two main types, pulse ionization chambers and gas multiplication proportional counters. In both these types, the ionizing particles produced in a neutron reaction yield output pulses considerably larger than those due to gamma interactions and residual activity. This permits pulse height discrimination to be performed in the associated electronic equipment and in general permits satisfactory neutron flux measurements

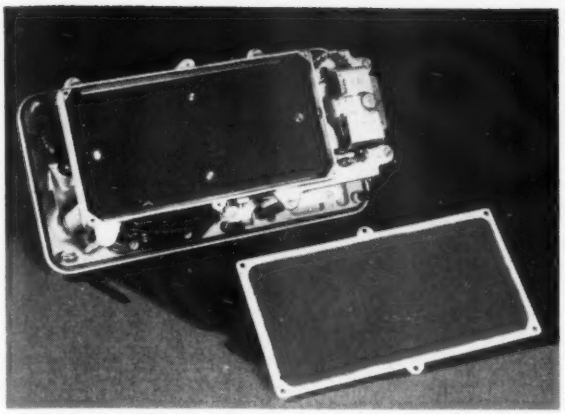

Fig 2 Slow-neutron survey meter, AERE Type 1399A, with boron-lined ionization chamber, can differentiate between slow-neutron and gamma-radiation hazards. Ranges 0–4000 and 0–40,000 n/cm²/sec

to be made in the presence of gamma backgrounds much higher than is possible with d.c. ionization chambers.

D.C. ionization chambers

These detectors have been made in a wide range of designs but the most common consist of an electrode system of either coaxial cylinders or parallel plates suitably mounted on insulating supports in a gas-tight case.

The use of coaxial cylinders is generally preferred since it permits the greatest possible electrode area to be obtained for a given size of case and also enables simple construction techniques to be employed.

The basic principles of construction may conveniently be discussed in relation to a chamber widely used for the detection of slow neutrons, the AERE Type RC 1, which has been described by Abson and Wade (*1*). A sectional drawing of this chamber is shown in fig 1. The electrodes consist of coaxial cylinders of aluminium, the inner used as the collecting electrode and the outer as the polarizing electrode. The adjacent surfaces of these electrodes may be left uncoated and the chamber filled with boron trifluoride gas to provide the neutron sensitive medium, or they may be coated with a layer of elemental boron and an inert gas filling used. This coating is extended over the cylindrical surfaces and the hemispherical end caps. The electrodes are supported on aluminium pillars which are welded to the electrode base plates and which are insulated from the main chamber end plate by means of quartz disks. The electrode system is enclosed in a cylindrical aluminium outer case, 3½ in. diameter and 9 in. long, which is welded to the base plate. A small pumping system permits evacuation of the envelope, outgassing and filling with the appropriate gas, after which it is sealed off.

As much as possible of the chamber is constructed of high purity aluminium (99·8 pct). The half life of Al-28, which is produced by neutron irradiation, is 2·3 minutes and by limiting long-lived impurities to a low level the current due to residual beta activity in the chamber components is reduced and the operating range of the chamber extended. Care is also taken that beta particles from steel components are absorbed in aluminium before reaching the sensitive volume.

Boron coatings are applied to the electrodes by painting or spraying and may be of natural elemental boron or boron highly enriched (92 pct) in B-10. The lighter isotope is only 18 pct abundant in natural boron and since B-11 has no useful reaction with neutrons the enriched material provides sensitivities of up to 5 times those obtained with the natural material. The electrode spacing used in the RC 1 is 6·2 mm and at this spacing about 90 pct of the energy of the n-α reaction is spent in the gas when the chamber is filled with hydrogen at a pressure of 150 cm Hg. As the gas pressure is reduced the gamma sensitivity falls more rapidly than the neutron sensitivity; the ratio of neutron to gamma sensitivity reaches a maximum at about 50 cmHg and remains constant below that.

The sensitivities of this chamber for various filling pressures and with coatings of natural and enriched boron are shown in table 1. These values refer to natural boron coatings of 1 mg/cm² and enriched coatings of 0·4 mg/cm², with coated area 500 cm² and sensitive volume 180 cc.

TABLE 1 Neutron and gamma sensitivities (S_n and $S\gamma$) for RC 1 ion chamber

gas pressure cmHg	S_n enriched B a/n/cm²/sec	S_n natural B a/n/cm²/sec	$S\gamma$ a/r/h
Boron lined			
150 H_2	$2{\cdot}4 \times 10^{-14}$	6×10^{-15}	$6{\cdot}0 \times 10^{-12}$
50 H_2	$1{\cdot}5 \times 10^{-14}$	$3{\cdot}8 \times 10^{-15}$	$2{\cdot}0 \times 10^{-12}$
15 H_2	$6{\cdot}0 \times 10^{-15}$	$1{\cdot}5 \times 10^{-15}$	$6{\cdot}0 \times 10^{-13}$
BF_3 filled			
30 BF_3	$2{\cdot}4 \times 10^{-14}$	$6{\cdot}0 \times 10^{-15}$	$1{\cdot}3 \times 10^{-11}$

These are the normal coating densities used and give the maximum possible sensitivity for a given gas pressure. Where reduced sensitivity is desirable it is preferable to reduce the gas pressure since this also reduces the gamma response. The polarizing potential required to saturate the chamber is a function of the ionization density which in turn depends on neutron flux, gas pressure and type of coating. For example with a boron coated RC 1 chamber, hydrogen filled to 150 cmHg, a polarizing potential of 400 volts will give more than 99 pct collection efficiency for a current of 7×10^{-5} amp. This corresponds to a flux of $1{\cdot}2 \times 10^{10}$ n/cm²/sec with a natural boron coating or about 3×10^{9} n/cm²/sec with an enriched coating. For operation at higher fluxes the collection characteristics can be considerably improved for a comparatively small reduction of sensitivity by reducing the gas pressure. At 50 cmHg the same polarizing supply will give more than 99 pct collection efficiency at a current of $3{\cdot}5 \times 10^{-4}$ amp, corresponding to fluxes of 6×10^{10} and $1{\cdot}5 \times 10^{10}$ n/cm²/sec for natural and enriched coatings. For an enriched BF_3 gas filling, at 30 cmHg pressure, the corresponding values are 10^{-5} amp at a flux of 4×10^{8} n/cm²/sec.

The current due to residual activity, induced in an ionization chamber when operating at a high neutron flux, may govern the level of flux at which measurements can be made subsequently when the high neutron flux is reduced. This effect is of importance in reactor instrumentation systems in d.c. channels used for control during start-up following a previous shut-down of the reactor.

TABLE 2 Residual activity for RC 1 ion chamber
(30 minutes and 8 hours after shutdown)

electrode coating	gas filling	I_R/I_N after 30 m	I_R/I_N after 8 h
enriched boron	H_2, 150 cmHg	$1{\cdot}6 \times 10^{-7}$	$5{\cdot}0 \times 10^{-8}$
enriched boron	H_2, 15 cmHg	$6{\cdot}5 \times 10^{-8}$	$2{\cdot}0 \times 10^{-8}$
none	BF_3 enriched 30 cmHg	$3{\cdot}0 \times 10^{-7}$	$9{\cdot}5 \times 10^{-8}$

Note For natural boron the values of I_R/I_N are about 4 times the values given in the table.

Table 2 shows values of the residual activity current I_R as a fraction of the neutron current I_N obtained when the flux was present. It will be seen that at times greater than 30 minutes after shut-down of a reactor, it is possible to

measure neutron flux levels in the region of 10^{-6} to 10^{-7} of the previous full-power levels.

The type RC 1 chamber is the principal ion chamber in current use for reactor control purposes in the UKAEA. A larger chamber, based on a design by Carmichael (*2*), is used for low flux measurements and for some health monitoring applications. This is the TPA chamber, which is larger than the RC 1, and has an active volume of 5 litres. For thermal neutron detection it is used with a boron trifluoride filling, the range of sensitivities available being shown in table 3. Because of the larger electrode spacings used (approx 1 in.) satisfactory ionization collection can only be obtained for high currents at low gas pressures. For example, at 7·8 cmHg BF_3 pressure, adequate collection at a current of 1 microamp requires a polarizing voltage of about 1000 volts. This current corresponds to a neutron flux of about 2×10^7 n/cm²/sec. The quartz-lead compression seal is used in this chamber and the outer case and end plate are made of steel. This provides a strong case which can be filled at high pressure but gives poorer residual activity characteristics than the RC 1. It may also be used as a fast neutron detector since its case will withstand high internal pressures and for this purpose it is filled to 20 atmospheres with hydrogen. The n-p reaction yields 'knock-on' protons which cause ionization and for 1 MeV neutrons a sensitivity of the order of 5×10^{-14} amp per neutron/cm² may be obtained.

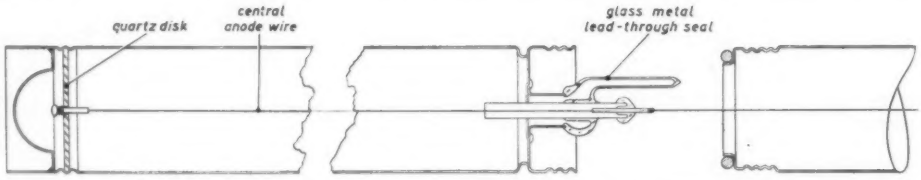

Fig 3 2 in. dia. BF_3 proportional counter. Walls of 0·03 in. oxygen-free copper give good vacuum characteristics

TABLE 3 neutron and gamma sensitivities in TPA ion chamber
(natural BF_3 fillings)

BF_3 pressure	S_n	$S\gamma$
cmHg	amp per n/cm²/sec	amp per r/h
7·8	6×10^{-14}	8×10^{-11}
20·7	$2{\cdot}3 \times 10^{-13}$	$2{\cdot}3 \times 10^{-10}$
40·3	$4{\cdot}1 \times 10^{-13}$	$4{\cdot}5 \times 10^{-10}$

Small parallel-plate boron-lined chambers have also been used for slow neutron health survey applications. Fig 2 shows an example of a portable, battery operated instrument, AERE Type 1399A, which incorporates a parallel-plate air-filled ionization chamber. A central collector plate is located between two polarizing electrodes with an inter-electrode spacing of about 0·5 cm. Four surfaces are coated with natural elemental boron and the ionization current for 2000 n/cm²/sec (the max permissible level equivalent to 7·5 mr/h of gamma radiation) is $1{\cdot}3 \times 10^{-12}$ amp. The inherent neutron/gamma sensitivity is adequate for differentiating between slow-neutron and gamma-radiation hazards. Thus, the current for 7·5 mr/h of gamma radiation is less than 2 pct of the current for a slow neutron flux of 2000 n/cm²/sec.

Proton-recoil counters

Fast neutrons may be detected by means of their elastic collision processes with other nuclei; hydrogen is a particularly useful target material as its scattering cross-section is larger than other light nuclei and the average energy of the recoils is greater than for heavier nuclei. In a gas-ionization detector the hydrogen may be used as a constituent of the counting gas or in the form of a solid 'radiator' inside the counter or in some combination of these two arrangements. The specific ionization of the recoil protons is greater than that due to electrons from gamma-interactions and hence it is possible to differentiate between neutron and gamma radiation by means of pulse-amplitude discrimination. It is usually necessary to make use of gas multiplication in order to obtain a voltage pulse from the counter which can be readily detected in a pulse amplifier. The sensitivity of these detectors is a function of the neutron energy and of the discriminator bias setting used. The sensitivity rises from zero when the energy of the recoil protons exceeds the discriminator bias setting. In a gas-recoil counter the sensitivity then rises rapidly to a maximum as the neutron energy is increased, and then falls gradually due to the decreasing value of the scattering cross-section. In a counter with a solid radiator, the sensitivity continues to rise with increasing neutron energy to much higher values. The sensitivity and pulse height distribution of a variety of forms of proton-recoil counter have been described by Rossi and Staub (*3*). A proportional counter, using a combination of gas recoils and recoils from a solid radiator, has been applied to the problem of fast neutron health monitoring (*4, 5*). In the counter described by Loosemore and Dennis (*5*) the bias setting can be adjusted so as to give a uniform sensitivity versus energy for neutrons in the energy range 3–14 MeV. Below 3 MeV the sensitivity falls with energy so as to compensate for the increasing permissible level of neutron flux*. Thus, with the correct setting of discriminator bias, the observed counting rate gives a measure of the fast neutron hazard irrespective of neutron energy.

Boron trifluoride proportional counters

The n-α reaction with B-10 is widely used for neutron detection in the thermal and epithermal energy region. The absorption cross-section is high (approx 4000 barns at 0·025 eV) so that high efficiency detectors are possible, and the variation of cross-section with neutron energy follows the 1/v law and is free from resonance effects up to energies of the order of 1 keV.

Fig 4 Oxygen-free copper and fluxless brazing techniques can be used for ½ in. to 2 in. dia of BF_3 proportional counters

In boron trifluoride counters, the gas acts as the source of B-10 and as the ionization-detection medium. The range of the charged particles liberated in the reaction

**In the range 3–14 MeV, the maximum permissible level for long term exposure to fast neutrons is 30 n/cm²/sec. Below 3 MeV this rises and at 0·1 MeV has a value of 200 n/cm²/sec.*

($^4He_2$ and $^7Li_3$, total energy 2·4 MeV) is about 0·5 cm in BF_3 gas at s.t.p. For counters in which the product of diameter and gas pressure is greater than about 0·5 atmo-cm it is possible to achieve 100 pct detection efficiency, i.e. sufficient ionization is produced by one or other of the ionizing particles to provide an output pulse which is greater than pulses arising from gamma-interactions.

Fig 3 shows a sectional drawing of a 2 in. diameter BF_3 proportional counter. The general principles of the design follow that of other types of gas proportional counter.

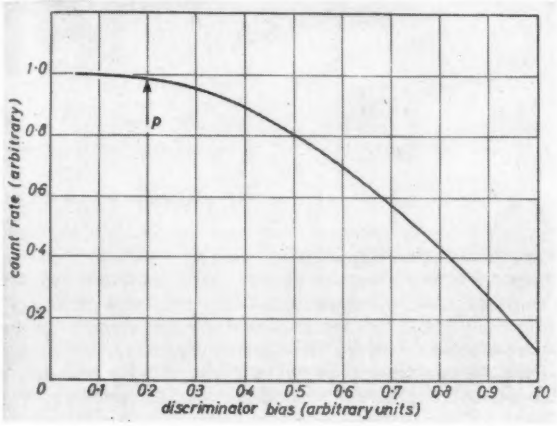

Fig 5 Counting rate/discriminator bias curve for BF_3 counter 6 × 1 in. dia. Gas pressure 40 cm Hg. Counting rate becomes independent of discriminator bias setting below level of about 0·2 of max pulse height

The electrons produced in the primary ionized tracks are attracted to the central anode wire and with a sufficiently high positive potential, secondary ionizing collisions occur and the final collected charge is thus amplified by a gas multiplication process. Special precautions are required in the preparation of the BF_3 gas to ensure that it is free from electron-capturing impurities and the counter bodies must also be capable of being thoroughly outgassed to prevent subsequent contamination of the gas and deterioration of the counting characteristics. In the design shown in fig 3, good vacuum characteristics are obtained by the use of oxygen-free copper as the main constructional material and by the use of fluxless brazing techniques for all joints. The same manufacturing techniques may be used for a wide variety of counter sizes and examples of counters with diameter ranging from 2 in. to $\frac{1}{2}$ in. are shown in fig 4. The design details of these counters and their electrical characteristics and performance are fully described elsewhere (6) and only a brief summary of their chief properties will be given here.

BF_3 proportional counters may be operated with gas multiplication factors, M, of several hundred times with the counter operating in the proportional region, i.e. the collected charge is proportional to the primary ionization. The anode voltage required depends on the anode and cathode diameters, and on the gas pressure. Some values are given in table 4 for M = 40 in a variety of counters. The voltage change required to change M by a factor 2 is of the order of 200 volts. Provided that no electrons are lost by electron-capture on impurities or by recombination with positive ions, the spread in pulse height is determined solely by wall effects, i.e. the extent to which particle energy is lost in the walls of the counter. Fig 5 shows the variation of counting rate with discriminator bias setting for a 1 in. diameter counter filled to a pressure of 40 cmHg. It will be seen that substantially all n-α events are registered at a bias level equivalent to about 0·2 of the maximum pulse height and the counting rate becomes independent of discriminator bias setting below this level. For larger diameter and/or higher gas pressures a longer plateau region is obtained on the discriminator bias curve. Conversely the plateau region is diminished in small diameter counters due to the increased wall effects.

Fig 6 shows a schematic circuit diagram of a proportional counter used with a pulse amplifier and amplitude discriminator. The voltage induced at the anode wire is due to the movement of the positive-ion sheath formed near the wire by the gas-multiplication process. This voltage rises rapidly at first, reaching about 50 pct of its maximum possible amplitude in about a microsec, and then increases more slowly as the positive ions drift outwards towards the cathode. The voltage wave-form at the anode is subsequently modified by the pulse-shaping circuits used in the amplifying chain. These are usually R-C differentiating and integrating circuits as shown in fig 6. When the time constants of these circuits (T_1 and T_2) are comparable with the rise time, T, of the counter pulse, the effective input pulse amplitude depends on T_1, T_2 and T, as well as on the gas multiplication M and the total input capacitance C.

It is convenient to refer to the counter output pulse in terms of the equivalent instantaneous charge collected. Thus, when the counter referred to in fig 5 is operated at the point P on the bias characteristic (0·2 of max pulse height) the input sensitivity of the amplifier is such that a charge of $5{\cdot}5 \times 10^{-14}$ coulombs will just trigger the discriminator circuit. The input charge sensitivity can be measured by injecting a voltage step function (V) through a series capacitance C_s, into the counter/amplifier input circuit; if C_s is small compared with the input capacitance C, the injected charge is C_sV. The equivalent charge $q = 5{\cdot}5 \times 10^{-14}$ coulombs (or $3{\cdot}5 \times 10^5$ ion pairs) applies to a case where $T_1 = T_2 = 0{\cdot}8$ microsec and the gas multiplication M is approx 40. The corresponding effective input voltage amplitude is $\frac{q}{C} \times \frac{1}{\epsilon}$, where the factor $\frac{1}{\epsilon}$ is the attenuation of a step function input, produced by the R-C differentiating and integrating networks when their time constants T_1 and T_2 are equal. If the triggering voltage of the amplitude discriminator circuit is V_T the gain required in the pulse amplifying stages will be $\frac{V_T}{q} \times C.\epsilon$.

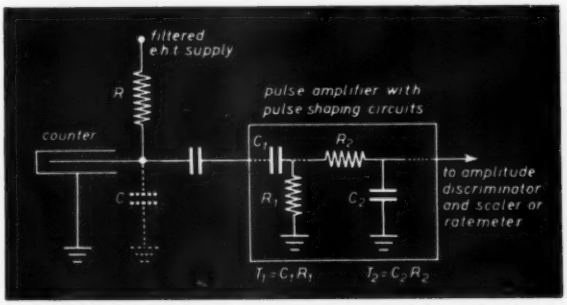

Fig 6 Schematic circuit of counter, pulse-amplifier and pulse-counting system

The value of the equivalent instantaneous charge q decreases as the differentiating and integrating time constants are reduced to values comparable with or less than the counter rise-time T; for $T_1 = T_2 = 0{\cdot}16$ microsec. q is reduced to about a half the value quoted for $T_1 = T_2 = 0{\cdot}8$ microsec.

Counter sensitivities may be estimated from the total cross-section of the B-10 within the sensitive volume.

Boron enriched in the B-10 isotope (95 pct B-10) is currently available for counter applications; the total cross-section for thermal neutrons of 1 ml of the BF_3 gas at s.t.p. is approximately 0·1 cm^2. If the fractional absorption of neutrons within the gas in the counter is small, the counter sensitivity in terms of counts per unit neutron flux is equal to the total B-10 cross-section in cm^2. Table 4 gives some details of the sizes and sensitivities of the counters shown in fig 4.

TABLE 4 Typical sizes and sensitivities of Boron Trifluoride Counters

cathode diameter in.	anode diameter in.	sensitive length in.	gas pressure cmHg	anode voltage for M = 40 volts	approximate sensitivity cps per unit thermal neutron flux
0·5	0·001	2	40	1200	0·3
0·5	0·001	11	40	1200	1·7
1·0	0·002	5	40	1800	3·0
1·0	0·002	12	70	2400	13·5
2·0	0·004	6	70	3500	27·5
2·0	0·004	16	70	3500	73
2·0	0·004	43	70	3500	196

Banks of large counters, in various geometrical arrangements, are used as high efficiency detectors in experiments on neutron absorption and scattering. The smaller-size counters have applications in the measurement of neutron-flux distribution and also in reactor instrumentation systems for the monitoring of neutron power at levels where pulse-amplitude discrimination is necessary to differentiate between neutron and gamma-radiation. Although individual pulses due to gamma-interactions are smaller than 'neutron pulses,' build-up of these pulses at high gamma-radiation levels will eventually mask the neutron pulses. The build-up effect is greater for the larger counters because the number of gamma interactions increases with the cathode area and the amplitude of the individual gamma pulses increases with counter diameter and gas pressure. The effect can be minimized by the use of short time constants in the pulse amplifier, so as to reduce the effective response time of the counter/amplifier system to a minimum value equal to the counter response time. A 6 × 1 in. diameter counter, filled with BF_3 at 40 cmHg may be used in the presence of gamma-radiation dose-rates of about 200 r/h. With differentiating and integrating time constants of 0·16 microsec the gamma-radiation effects can be rejected with the discriminator circuit set at a level greater than about 0·2 of the maximum pulse height, i.e. point P in fig 5.

Fission counters

In fission counters, a thin layer of the fissionable material is deposited on the electrode surface. The energy of the fission fragments resulting from the absorption of a neutron is some 160 MeV and the particle ranges are very short, e.g. of the order of 1 cm in argon at atmospheric pressure. It is not therefore necessary to make use of gas multiplication and an easily detectable, fast-rising voltage pulse is obtained due to the collection of the electrons produced in the ionized tracks between the plates of a two-electrode ionization chamber.

The counters are used with a pulse-amplifier and discriminator unit in the same way as boron trifluoride proportional counters. Pulse build-up effects due to gamma-radiation do not become prohibitive until very high gamma-radiation dose-rates are reached, and the limiting level of dose-rate is more than 100 times that of a BF_3 counter of comparable size. On the other hand, for a given size of counter it is not possible to attain the high thermal neutron sensitivity of a BF_3 counter. The design

Fig 7 Fission counters with cathode areas ranging from 3 to 15,000 cm^2

criteria and electrical characteristics of a variety of fission counters used for reactor-control instrumentation and for neutron-flux distribution measurements, have been described by Abson, Salmon and Pyrah (7), and some examples of counters of varying sizes are shown in fig 7. In some cases the electrodes consist of a series of concentric interleaved cylindrical tubes so that the maximum cathode area, and hence maximum sensitivity, can be obtained in a given overall size of counter. Fig 8 shows a sectional drawing of a cylindrical counter with a single central anode. The fissionable material is deposited on the separate cathode sleeve.

With coatings of the order of 0·1 mg/cm^2, one or other of the fission fragments emerge from the coating into the gas space between the electrodes and a 100 pct detection efficiency is obtained. Coating thicknesses up to 1 or 2 mg/cm^2 may be used in order to increase the counting sensitivity per unit area, but the efficiency is then reduced, by complete absorption of some of the fission fragments within the coating, to a value of some 60–70 pct. Fig 9 shows counting rate/discriminator bias curves for various thicknesses of foils in a parallel plate chamber. It will be seen that for a coating thickness greater than 2 mg/cm^2, the plateau characteristic of the discriminator bias curves is deteriorating. The bias level is given in terms of the equivalent instantaneous charge and it will be seen that the value at a typical operating point in the plateau region is about 0·4 × 10^6 ion pairs. With a gas filling of A + 2 pct N_2 the product of gas pressure and electrode spacing should be about 1·0 atmo-cm in order to attain maximum pulse height, and a polarizing voltage of 500–1000 volts is then required in order to avoid appreciable recombination of the primary ionization before collection. The electron-collection time, which determines the rise-time of the counter pulse, is a small fraction of 1 microsec and the equivalent instantaneous charge q does not change appreciably with changes in the amplifier time constants down to 0·2 microsec. Counting rates up to some 3 × 10^5 cps can be registered with counting losses less than 10 pct; this compares with a value of about 10^5 cps for a BF_3 proportional counter with rise-time of about 1 microsec.

U-235 is used when the highest thermal neutron sensitivity is required. The neutron/fission cross-section at thermal energies is 590 barns, and the counting response of a counter containing 1 g of U-235 with a coating thickness of 1 mg/cm^2 is approximately 1 cps per unit thermal neutron flux. The large counter shown in fig 7, which has a total cathode area of 1500 cm^2 can thus be used with

a U-235 coating of some 1·5 g and a sensitivity of 1·5 cps per unit thermal neutron flux. The maximum sensitivity of a fission counter is limited by the electrical capacitance and also by the alpha activity in the fissionable coating, and it becomes impracticable to consider thermal neutron sensitivities (using U-235) greater than a few cps per unit flux. The intermediate sizes of counter shown in fig 7 and the counter shown in fig 8 have cathode areas of the order of 100 cm² and with U-235 coatings may have thermal neutron sensitivities of up to about 0·1 cps per n/cm²/sec. Very small, low sensitivity counters have been used up to flux levels of the order of 10^{10} n/cm²/sec and could if necessary be used at higher fluxes if the sensitivity were suitably reduced to limit the counting rate to a maximum of 10^5 cps. The upper level of neutron flux will be set by the level of the accompanying gamma radiation; small $\frac{1}{4}$ in. diameter counters may be used in the presence of gamma radiation up to levels of 10^6 r/h.

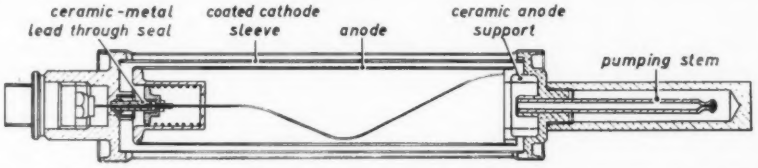

Fig 8 Cylindrical fission counter with single central anode. Cathode area 200 cm²

Fission counters are also used with appropriate fissionable materials for fast neutron measurements. Thus, U-238 and Th-232, with neutron/fission thresholds in the region of 1 MeV may be used in conjunction with thermal neutron detectors for the estimation of fast and slow neutron components in reactor core assemblies.

The range of usefulness of slow neutron d.c. ionization chambers extends, in the absence of gamma background, from fluxes of the order of a few neutrons/cm²/sec to 10^{11} neutrons/cm²/sec or higher. However, the presence of gamma fluxes, unavoidable in reactor installations, and considerations of residual activity impose restrictions on their use. At very low fluxes the currents obtained are very small and suitable precautions must be taken in their measurement. In reactor installations the lowest current that can satisfactorily be measured is of the order of 10^{-12} amps, and in the most sensitive RC 1 ion chamber this corresponds to a flux of about 50 neutrons/cm²/sec. In such a chamber a similar response would be obtained at a gamma radiation of about 0·2 r/h, and for measurements to be made at these low fluxes in the presence of gamma background some shielding round the chamber is necessary. A pure lead shield 4 in. thick would reduce the intensity of the gamma radiation in a reactor thermal column by a factor of 100 and provide a useful extension of the range of the detector. A further extension of about a decade may be obtained by the use of a gamma-compensated chamber in which the gamma response of the neutron chamber is backed off by the output of a second chamber sensitive only to gamma radiation. Current due to residual activity also limits the overall range of an ion chamber to some six decades and chambers which are normally only used at low levels may require shielding or withdrawal from the neutron flux at full power to prevent the build-up of high activities. The limitations at high neutron flux levels are due mainly to the difficulty of ionization collection.

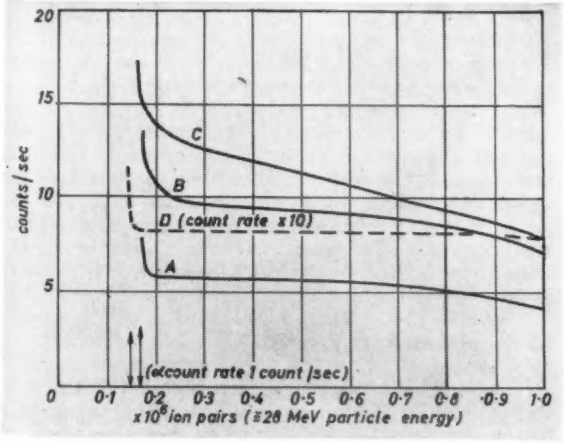

Fig 9 Fission counter sensitivity depends on thickness of fissionable material rating (U_3O_8). Counting rate/discriminator bias curves for cathode coating in mg/cm² of 1·0 (A), 2·1 (B), 3·2 (C) and 0·12 (D)

Pulse-type gas-ionization counters using the B-10 reaction or the fission process can be used in conjunction with pulse amplitude discrimination for the measurement of low neutron flux levels in the presence of high gamma radiation dose-rates. A range of sensitivities is available by the use of various sizes of counter, but the maximum counting rate with a particular counter is limited to about 10^5 cps. For example, a BF_3 counter with overall dimensions of 6 × 1 in. dia may have a sensitivity up to 5 cps per n/cm²/sec and may thus be used for flux measurements up to 2 × 10^4 n/cm²/sec. The lower level of flux measurement is governed by statistical fluctuations in the counting rate, and for reactor control applications will be of the order of 10 n/cm²/sec (= 50 cps). In this size of counter, discrimination against the pulse build-up effects from gamma radiation is possible up to dose-rates of a few hundred r/h. A U-235 coated fission counter of similar size may have a sensitivity up to 0·1 cps per n/cm²/sec. A counting-rate range of 50 to 10^5 cps will thus correspond to a neutron flux range of 500 to 10^6 n/cm²/sec and discrimination against gamma radiation will be possible up to dose-rates of about 10^5 r/h.

Gas-ionization chambers and counters have so far proved to be the most suitable type of detector for the majority of neutron measurements required in nuclear reactors, because of the wide range of measurement possible and their ability to withstand long radiation exposures without damage. Although solid state detectors such as the scintallation counter may be used to give higher neutron sensitivity (by virtue of condensing the neutron detecting material into a small space), their gamma sensitivity is also increased and they are limited to applications where the gamma dose-rate is low. They are also less resistant to radiation damage and are less suitable for use at elevated temperatures than gas-ionization detectors.

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4 SCINTILLATION NEUTRON COUNTERS

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SCINTILLATION COUNTERS are now widely used to detect with high efficiency uncharged radiation in the form of gamma rays, but their use for detecting uncharged radiation in the form of neutrons has not been such an unqualified success, and no simple fast or slow neutron detecting phosphor has yet emerged which is of such widespread application as is for example NaI-Tl for gamma rays. But there are a number of different types of scintillation neutron detectors from which it may be possible to choose one to suit a particular problem.

Neutrons are seldom produced without a multiplicity of gamma rays. For example, in fission about three gamma rays are produced per neutron whilst Ra-Be neutron sources produce about 10^4 gamma rays per neutron and even Po-Be produces about 1 gamma ray per neutron. The probability that the gamma ray will produce a secondary electron within the phosphor is generally of the order of 10 pct per cm path. The relative gamma and neutron detecting efficiencies will therefore be of some importance in almost all neutron detectors. An exception occurs where a pulsed neutron source is used in conjunction with time of flight techniques; in this case gamma sensitivity is of less importance provided it does not contribute appreciably to background.

1. SLOW NEUTRON DETECTORS

1.1 Neutron capture gamma ray detectors

Slow neutrons can be detected by the prompt radiation emitted when they are captured by some target nucleus. A detector of this type is used with the time of flight spectrometer on the Harwell linear accelerator (*1*). In this case a block of elemental boron enriched in B-10 is placed in the neutron beam. The $^{10}B(n\alpha)^7Li$ reaction results in the emission of a 0·478 MeV gamma in 93·5 pct (*2*) of cases of thermal neutron capture. This gamma ray is then detected by thallium activated sodium iodide crystals which are shielded from background gamma radiation and from the main neutron beam, which includes a paralysing gamma flash. For time of flight work this arrangement has the advantage of small timing uncertainty and can be used for neutron energies up to 1 keV. The detection efficiency depends on the product of the solid angle subtended by the NaI-Tl crystals and their detection efficiency for the 0·478 MeV gamma ray. Owing to the high detection efficiency of NaI to stray gamma radiation and due to K-40 and other activities in the phosphor and the multiplier photocell, shielded backgrounds of the order of 1 cpm per g NaI might be expected. Effective background can be reduced by a factor of about 5 for this application by use of pulse height selection on the NaI-Tl crystals.

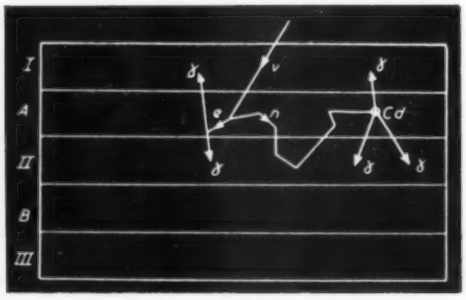

Fig 1 Apparatus for detecting neutrino capture (section 1.2) A and B are tanks of cadmium solution, I, II and III are separate tanks of liquid scintillator. The neutrino reacts with a proton to produce a positive electron and a neutron. The position is detected by coincident pulses from the annihilation radiation, and the neutron which takes a few microsec to become thermalized, is detected by the coincident gamma rays produced when it is captured in cadmium

1.2 Coincidence capture gamma ray detectors

Another method by which background can be reduced on a capture gamma ray neutron detector is to use as a target a material giving several gamma rays per neutron capture, and to detect these in coincident gamma detectors (*3*). For example Cd (gamma multiplicity 4·1) or Sm (gamma multiplicity 5·6) might be used. As a result of the coincidence detectors however, efficiencies might be expected to be low unless very large secondary detectors are used. Such a system using liquid scintillators of dimensions of several feet was used by Cowan, Reines et al (*4*) to detect the neutrino.

1.3 Boron-ZnS(Ag) mixtures

As an alternative to detecting neutron capture gamma rays, a target nucleus from which a charged particle is emitted when a neutron is captured might be chosen; for example the $^{10}B(n\alpha)^7Li$ reaction might be used in which the alpha particle and Li nucleus share 2·320 MeV (Q = 2·793 MeV). Scintillators utilizing this reaction include ZnS and B_2O_3 fused together as a glass or mixtures of ZnS and a boric acid-glycerine polyester.

Optimum design of these phosphors consists of essentially the maximum thickness of ZnS(Ag) phosphor which is transparent to its own scintillations together with the minimum amount of boron loaded binder necessary to hold it together. Sun, Malmberg and Pecjak (*5*) report that a counting efficiency of 21 pct is obtained for the natural boron-ZnS(Ag) polyester plastic system if the gamma flux does not exceed 0·1 mr/h. Thus a 2 in. dia disk can be expected to give 4 counts/neutron/cm² to a flux of thermal neutrons at normal incidence to the disk. (This may be compared with a 1 in. dia × 6 in long proportional

counter filled to 70 cm pressure of BF_3 enriched in B-10, which would give 5 counts/neutron/cm², or a 2 in. dia × 9 in. long BF_3 counter, which would be of similar size to 2 in. disk and multiplier photocell, and would give 24 counts/neutron/cm² if filled with 70 cm BF_3-10.)

When the gamma ray background is much greater than 0·1 mr/h, the operating bias level must be raised if gamma rays are not to be registered as neutrons. Fig 2 shows the bias curves obtained with a 5 in. dia B-10 polyester plastic disk when irradiated with thermal neutrons and Co-60 gamma rays. A gamma background of the order of 1 rad/h involves a serious sacrifice of neutron counting efficiency. By comparison a 2 in. dia × 9 in. long BF_3 counter can be used in gamma fields of order 50 rad/h. With the phosphors however, the concentration of the sensitive volume into a thin layer results in a small timing error for time of flight purposes and detectors of this type have been selected as the most suitable for the Harwell fast chopper. Efficiencies of the order of 3 pct are expected for 1 keV neutrons (*6*).

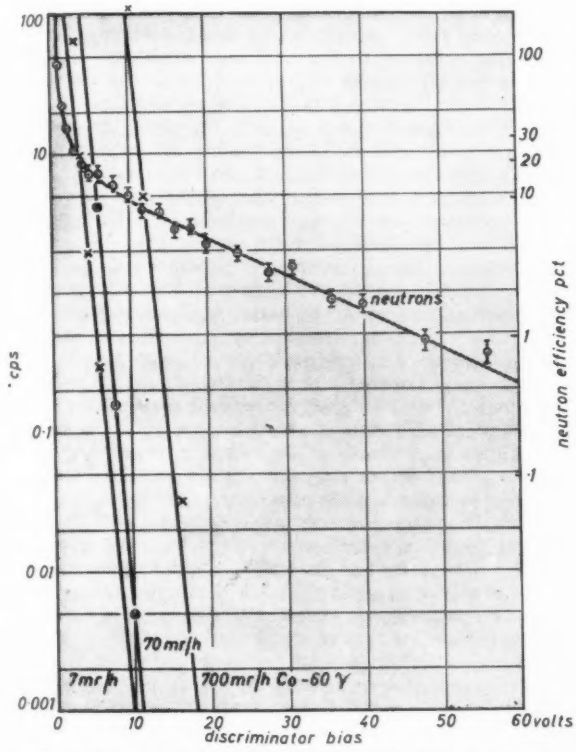

Fig 2 Bias curves for boron plastic –ZnS (Ag) system. 5 in. phosphor. 88 pct B-10, when irradiated with thermal neutrons and gamma rays

1.4 Gas scintillators

Gas scintillators have been suggested as suitable for detecting heavy charged particles emitted on neutron capture by elements such as B-10 or U-235. They consist essentially of a noble gas as free as possible from molecular impurities, and as most of the light is emitted in the ultra-violet, a converter such as quaterphenyl may be used which absorbs the u.v. and re-radiates visible light suitable for the photomultiplier (*7*).

The efficiencies and interference from gamma radiation expected from this type of detector are about the same as one might expect from gaseous detectors of similar dimensions employing charge collection; the pulse amplitude resolution is rather worse, but the pulses have been reported as having rise times of the order of 10 millimicrosec and full widths at half max of 20-30 millimicrosec (*8, 9*). This is 10 to 100 times faster than one might expect when using charge collection.

The use of a 10 pct Xe-90 pct He mixture has been suggested (*10*) as suitable for use as a high efficiency neutron counter employing the $^3He(np)^3H$ reaction (Q = 0·78 MeV).

1.5 Boron loaded liquid scintillators

Unfortunately no inorganic boron containing phosphor has yet emerged which is available in large clear volumes. Boron has however been introduced as methyl borate and in other forms into organic solution scintillators (*11*). In these scintillators, if they are of small size, the gamma ray escapes and the scintillation results from excitation by the alpha particle and the Li-7 recoil. A major drawback with all organic scintillators however, is the much lower light output per MeV from the more intensely ionizing particles, the light output from electrons, protons, and alpha particles of the same energy being roughly in the ratio 1:0·3:0·07. Bollinger and Thomas (*12*) report that the scintillation intensity from the boron disintegration products in a liquid scintillator produce a pulse equal to that for a 40 keV electron, and as a result the scintillator signal is comparable in magnitude to photomultiplier noise pulses. Fairly elaborate arrangements of coincidences, cooling etc may thus be necessary if this system is to be utilized. Detection efficiences with such an arrangement however can be extremely high. Bollinger and Thomas, using a liquid scintillator containing 50 pct methyl borate (96 pct B-10) find efficiencies of 92 pct at 1 eV and 50 pct at 1 keV from a path length of 5 cm in the phosphor. Gamma sensitivity however will be of the order of 4-10 pct/cm, though pulse height selection might be used here to improve the neutron/gamma ratio. The light output from these types of scintillator has been materially improved by use of naphthalene as a secondary solute.

1.6 Lithium Iodide-europium crystals

LiI-Eu by use of the $^6Li(n\text{-}\alpha)^3H$ reaction (Q = 4·80 MeV), also offers a possible method of detecting thermal neutrons, with high efficiency (approx 90 pct for thermal neutrons and approx 3·5 pct for 1 keV neutrons for 2 in. thick crystal using nat.Li). It is however extremely difficult to prepare and to keep. In addition LiI-Eu is no less efficient than NaI-Tl for detecting gamma rays. Use of LiI enriched in Li-6 (7 pct in nat.Li) to some extent overcomes this limitation. Neutron activation of the iodine may also limit the usefulness of this material. (If the detection efficiency in a 2 × 2 in. crystal were 100 pct it would give about 20 counts/thermal neutron/cm²—about the same for thermal neutrons as the BF_3 counter 2 in. dia × 9 in. long discussed in para 1.3.) By cooling selected ^{6}LiI-Eu crystals to −196°C Murray (*13*) has shown that monoenergetic neutrons of 2·9 and 14·4 MeV produce well defined peaks of full width at half maximum of 14 pct and 6 pct respectively. Consequently these crystals can be used as a fast neutron spectrometer with efficiencies of the order of 0·1 pct.

1.7 Particle multipliers

Though not strictly a scintillation method, electron multiplier techniques might be used to obtain high speed detection.

For example if a U-235 surface is coated with a suitable layer, perhaps BeO, 40-100 low energy secondary electrons will be ejected per fission fragment (*14*). These could be collected into an electron multiplier thus eliminating the necessity for a phosphor. Such an arrangement might be

expected to have a neutron to gamma discrimination comparable with, or even better than pulse ionization chamber devices.

1.8 Alternative methods

It might also be noted that NaI-Tl has been used as an activation method of monitoring slow neutrons using the 25 min I-128 decay (2 MeV beta) or the 15 h Na-24 decay (cross sections 6·3 barn and 0·6 barn respectively). Similarly the exposure of individuals to neutron fluxes might be determined by the induced activity in Na-24 in the body by means of body monitoring techniques using NaI-Tl scintillation counters (*15, 16*). A whole body slow neutron irradiation equal to 3 h at 1 m.p.l. will produce Na-24 gamma activity about equal to that of natural K-40, i.e. of the order 10 times the detectable limit.

2. FAST NEUTRON DETECTORS

2.1 General

Organic phosphors can be used as an activation method to detect neutrons above 20·4 MeV by the $^{12}C(n,2n)C^{11}$ reaction as described by Sharpe and Stafford (*17*) C-11 decays by 1 MeV positron emission with a half life 20 min. The cross section for this reaction at 90 MeV is 0·02 barn. More usually however fast neutrons are detected by means of the hydrogen scattering process which gives rise to proton recoils. Any organic phosphor can be used for this purpose but the relatively poor response of the organic scintillator to proton excitation usually limits its application to neutrons of greater than 500 keV energy. If we consider the organic phosphor as approximating to $(CH)_n$ the relative cross sections for the production of ionizing particles by gamma rays and neutrons can be seen to be comparable from table 1.

Table 1

	H(nn)H scattering cross-section per (CH)	Compton scattering cross-section per (CH)
100 keV	12·5 barn	3·5 barn
1 MeV	4·5 „	1·5 „
10 MeV	1·0 „	0·5 „

Neutron detection efficiencies are thus of order 10-20 pct/cm path i.e. two or three times the gamma detection efficiency.

2.2 Hornyak buttons

Efforts have been made to improve the neutron-gamma discrimination by separating the functions of scatterer and detector. G. N. Harding (*18*) describes an attempt to match the refractive index of KI-Tl with a hydrocarbon oil. Later Hornyak (*19*), described a mixture of ZnS and a hydrogenous plastic, e.g. Lucite. With these detectors (Hornyak buttons) gamma sensitivity is reduced because secondary electrons only dissipate a small fraction of their energy within a phosphor grain. As with the B-ZnS mixtures for slow neutron detection, the thickness of ZnS which can be used is limited by its high refractive index (μ = 2·3) and optimum design for the Hornyak button is 1·5 g ZnS mixed with 10 g Perspex, and compressed into a disk about 1 cm thick. Owing to light losses due to scattering from different points in the disk, there is a wide variation in the amplitude of the detected light pulses. Neutron detection efficiency therefore depends on the bias setting chosen, and is usually of the order of 1 pct for 5 MeV neutrons. In an effort to improve further on this type of detector, small spheres of plastic phosphor, of diameter approximately equal to the range of a recoil proton, were disposed throughout a non-hydrogenous medium such as carbon tetrachloride or other totally halogenated hydrocarbons. The liquid is introduced to absorb as much energy as possible from the secondaries produced by gamma rays. Higher efficiencies are obtained than with Hornyak buttons, but gamma suppression is still not very good.

2.3 Fast neutron detectors for health instrumentation

The ICRP recommendation on the maximum permissible flux levels (m.p.l.) for neutrons of various energies is given in table 2.

Table 2

Neutron energy	max permissible level neutron flux	1 m.p.l.
·025 eV	2000 n/cm²/sec	5×10^{-4}
10 eV	2000	5×10^{-4}
10 keV	1000	10×10^{-4}
0·1 MeV	200	50×10^{-4}
0·5 MeV	80	125×10^{-4}
2 MeV	40	250×10^{-4}
3–10 MeV	30	330×10^{-4}

To give an accurate assessment of the hazard therefore, neutron detectors with a response inversely proportional to the m.p.l. are required.

Moyer (*20*) has shown that the number of protons which are ejected from the surface of a thick hydrogenous radiator is proportional to the total neutron energy incident; mixtures of ZnS in a hydrogenous medium or deposits of ZnS on a hydrogenous backing can thus be used to indicate this quantity.

Keep (*21*) considered the use of Hornyak buttons for health instrumentation. He finds that with a 12·5 cm dia scintillator at a bias setting where 100 m.p.l. of gamma radiation produces 2 cps, 1 m.p.l. of 5 MeV neutrons produces 8 cps, and the count rate due to 1 m.p.l. of 500 keV neutrons at this bias would be about 2 cps.

Thompson (*22*) describes a counter consisting of $\frac{1}{8}$ in. thick walled hollow polythene sphere 7 in. in dia coated internally with ZnS, viewed by a 2 in. dia end window photomultiplier. He finds neutron sensitivity varies directly with gamma sensitivity, both sensitivities being functions of energy. With 100 mr/h (approx 13 m.p.l.) Ra gamma radiation 'biased out,' the counter sensitivity is 10 cps for a flux of 1 m.p.l. of Po-Be neutrons. From Keep's data one might expect this sensitivity to be halved if about 100 m.p.l. of gammas are present and are biased out.

With Thompson's and Keep's system the count rate per unit neutron flux is directly proportional to neutron energy so that measurement of biological hazard requires a knowledge of this mean neutron energy from some other source. In an effort to obtain a 1 m.p.l. characteristic, Skjöldebrand (*23*) describes a spherical counter of about the same size as Thompson's. The thickness of the hydrogenous radiator was 9·2 mg/cm² over most of the sphere but over 19 pct of the active area the radiator was 100 mg/cm² covered with 29 mg/cm² Al foil. In this way he was able to obtain a good approximation to the required characteristic. Again neutron sensitivity varies with gamma sensitivity; Skjöldebrand reports that when 200 mr/h of Ra gammas (about 30 m.p.l.) is 'biased out' the fast neutron sensitivity is about 1 cps/m.p.l. of fast neutrons.

A gas ionization detector has been designed to give a response suitable for measuring neutron dose in terms of m.p.l. by Dennis and Loosemore (*24*). It consists essentially of a tubular counter 6 in. long × 2 in. dia containing three cells lined with polythene. An approximate 1 m.p.l. response is obtained by suitably adjusting wall area and gas pressure. It is found that from this counter a counting rate of 0·9 cps is obtained for 1 m.p.l. of fast neutrons. Among the main advantages of this type of counter is the lower gamma sensitivity, 360 m.p.l. of gamma rays producing a reading corresponding to one-third of a fast neutron m.p.l. Secondly the gas itself is used as a detector for the very

low energy neutrons, with a result that a much better approximation to the 1 m.p.l. curve is obtained than appears possible from Skjöldebrand's data.

2.4 Organic scintillators for fast neutron detection

None of the ZnS-Ag methods of detecting hydrogen recoils allows efficiencies much higher than about 1 pct in even quite small gamma fluxes. Where higher efficiencies of neutron detection are required, some way must be found of overcoming the high gamma sensitivity of the large transparent organic phosphors which results from the comparable scattering cross-sections of gamma rays and neutrons, and the fact that the light output from recoil protons is only about one-third of that from electrons of the same energy. One approach to this problem has been to incorporate boron or cadmium with the phosphor. A fast neutron then produces a pulse corresponding to the early knock-on proton followed by disintegration products or capture gamma rays arising from capture of the thermalized neutron occurring some time later. Large tanks of liquid scintillator are required to ensure that the neutron is not lost by diffusion out of the tank, and also, if gamma detection is used, to obtain a high probability of detecting at least one of the capture gamma rays.

Reines et al (*25*) describe a large tank (dimensions of the order of feet) in which the neutron capture pulses have a maximum probability of occurrence about 2 or 3 microsec after the initial recoil event. Thus neutrons are identified as delayed coincident pulses. Where large scintillators like this are required, gamma efficiency will be very high so that there may be an appreciable random coincident rate due to background gamma flux.

Another very powerful method of reducing the gamma sensitivity of organic phosphors has been recently demonstrated by Brooks (*26*). Wright (*27*) first reported differences in decay time between pulses originated by electrons and alpha particles for stilbene and anthracene. It was further shown by Brooks that many organic phosphors possessed this property and that it could be used to differentiate between pulses originated by neutrons and by gamma rays. The effect is exhibited by a large number of phosphors. Best gamma ray discrimination is shown by stilbene, but good results can be obtained by almost all the crystalline phosphors, and with well deoxygenated liquid phosphors, including those containing naphthalene as a secondary solute to increase the scintillator efficiency of solutions containing boron, Cd etc. With Tolan and with the plastic phosphors so far tested the effect appears to be absent.

The main difference between alpha particle, proton or electron pulses appears to lie in the long lived components (approx 100 millimicrosec) of fluorescence decay time (*28*). It is thus not essential to use extremely fast multipliers which can follow the fast components (approx 5 millimicrosec), consequently photomultipliers 5 in. in dia with the relatively slow venetian blind dynode systems are quite satisfactory for the purpose. Attempts have been made to test whether the new 12 in. dia EMI multipliers can be used but this does not appear possible at the moment due to the very low fields and large differences in collection times between the centre and edges of the photocathode.

It is thought that a fast neutron detector having an efficiency of at least 20-50 pct and a gamma efficiency of about 0·1 pct or less will be obtainable for neutron energies above 500 keV.

The method may also be adopted to reduce the gamma sensitivity of the boron loaded liquids for slow neutron detection, though in this case good gamma discrimination may be difficult due to the statistical fluctuation likely in the number of photoelectrons produced by the low intensity of scintillation from the B-10 reaction. Capture of the 0·478 MeV gamma rays in large detectors might also prove a source of difficulty, but work is actively proceeding along these lines.

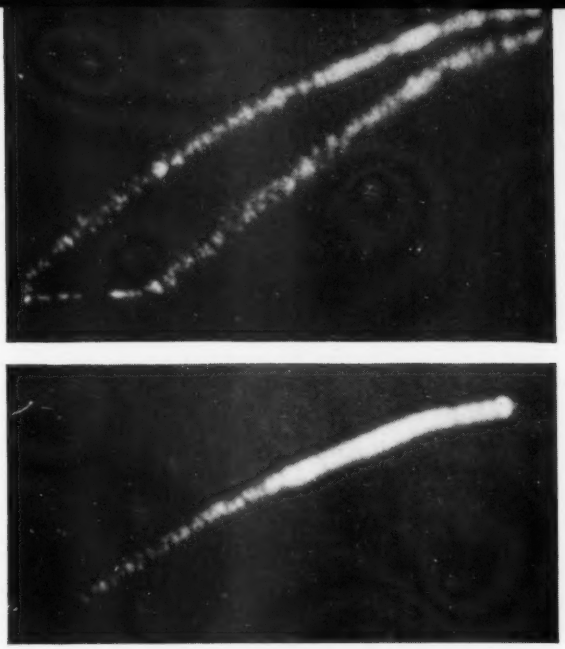

Fig 3 Differences in fluorescence decay time under gamma ray and neutron excitation (2.4). Each scintillation in stilbene is presented as a spot on a c.r.t. face, the X-deflexion being proportional to the total light emitted and the Y-deflexion dependent on the peak light intensity. A is obtained from thorium gamma rays and B from a Po-Be source which emits neutrons and gamma rays

At present the only simple scintillation phosphors suitable for fast and thermal neutron counting in the presence of high gamma fields are those based on ZnS-Ag mixed with either boron or a hydrogenous medium. These have gamma sensitivities at least an order of magnitude greater than have gas ionization devices of the same neutron sensitivity. Moreover the scintillation counters have, size for size, including the photocell container, approximately the same or lower overall sensitivities. Scintillation neutron counters do have advantages when no gamma rays are present, in particular for time of flight work where much smaller timing uncertainties are possible. Higher efficiencies can also be obtained in the epithermal region which is also appropriate to this application.

Higher neutron sensitivities using transparent organic phosphors may shortly become available which will seriously compete with the gas counters. No detectors exist covering the 20-200 keV range of neutron energies.

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5 REACTOR INSTRUMENTATION SYSTEMS

Three main types form the basis of Britain's power and research reactor programme. These diagrams have been specially prepared for NUCLEAR POWER to show their main instrumentation features

A gas-cooled reactor

Britain's programme for nuclear power is based solidly on the natural-uranium, graphite-moderated, gas-cooled reactor as typified by the Hunterston power station, now under construction for the South of Scotland Electricity Board by the GEC Simon-Carves group. All the power stations for installation in the UK have two reactors but in each case they will have centralized control rooms.

The electrical output is governed primarily by the coolant flow rate, controlled by the speed of the gas circulators. The temperature rise of the CO_2 in the reactor core is maintained approximately constant by adjusting the neutron flux to match the coolant flow, while the fall in the steam-raising units depends on the saturation steam temperatures—maintained approximately constant by the pressure regulators. During start-up, and up to 25 pct full power, the station is manually controlled. The circulators are operated at low speed and steam passed to the dump condensers until steam conditions are satisfactory for starting the turbines.

The CO_2 circulators are driven by d.c. motors supplied by grid-controlled mercury-arc rectifiers, giving accurate speed control over a range of 20:1. Adjustment may be manual, or by an automatic loop which compares the measured flow with the pre-set desired flow.

Neutron flux is controlled by boron-filled rods driven from low-frequency synchronous motors. The rods are arranged in groups to allow some spatial flux adjustment, with a safety group used only for emergency shut-down. Manual control is normally used, but the 'fine' group may be automatically controlled if desired, thus maintaining the flux approximately proportional to the coolant flow.

The six 60 MW steam turbines are driven by dual-pressure steam generated in the steam-raising units. The boiler steam pressure is controlled by the turbine throttle valves which maintain a constant pressure on their upstream side. Saturation steam temperature in the boiler is maintained nearly constant over the full power range. H.p. and l.p. steam pressure may be set from the control room, giving a convenient means of adjusting the lower CO_2 temperature. During start-up, or under special conditions, the turbines may be speeder governed, either locally or from the control room.

A fast-breeder

The great advantage of fast reactors seen at present is that they can produce more fuel than they consume by the process of 'breeding' fresh fissionable material such as plutonium-239 or uranium-233 from the non-fissionable but 'fertile' materials, uranium-238 or thorium-232 respectively. There are, however, many practical problems with fast reactors and it is to investigate these that the big Dounreay Fast Reactor is being build by UKAEA. It will be in operation later this year and is the largest fast breeder in the world.

Like all fast reactors, DFR has a very small core, but since 60 MW of heat will be generated, liquid sodium or sodium/potassium alloy has to be used as coolant. This is done in 24 primary heat exchangers and the heat is transferred to secondary liquid metal circuits, and hence to water in further heat exchangers where superheated steam is raised to drive a 15 MW turbogenerator set. The primary circuits are connected in pairs—shown on the diagram—to feed one secondary circuit. The primary and secondary sodium is pumped round the circuits by electromagnetic pumps—one for each primary circuit, two to each secondary.

Nuclear measurements are broadly similar to those on thermal reactors. The main ion chambers are located in the belt of borated graphite which surrounds the core tank and forms a thermal shield and recorders for period, power, log power and flux are provided. Reactor control is achieved by withdrawing twelve sections of the core by means of a complicated mechanism working below the surface of the liquid metal; there are also some boron safety rods. Position of these various control elements is shown to the operators by means of ordasigns or illuminated annunciators.

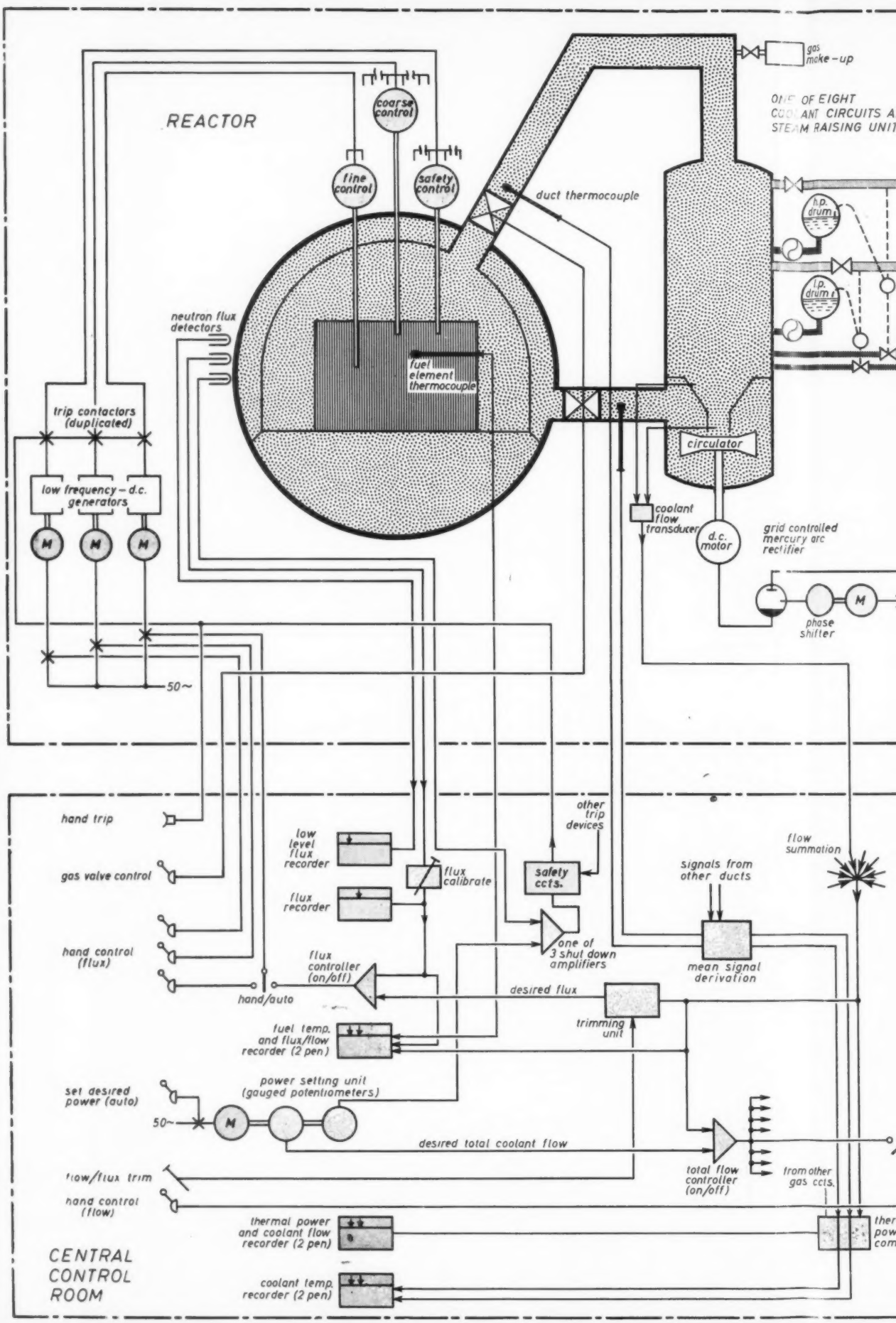
Fission products have little effect on fast neutrons, so there is nothing comparable to the fission product detection system of a gas-cooled power reactor.

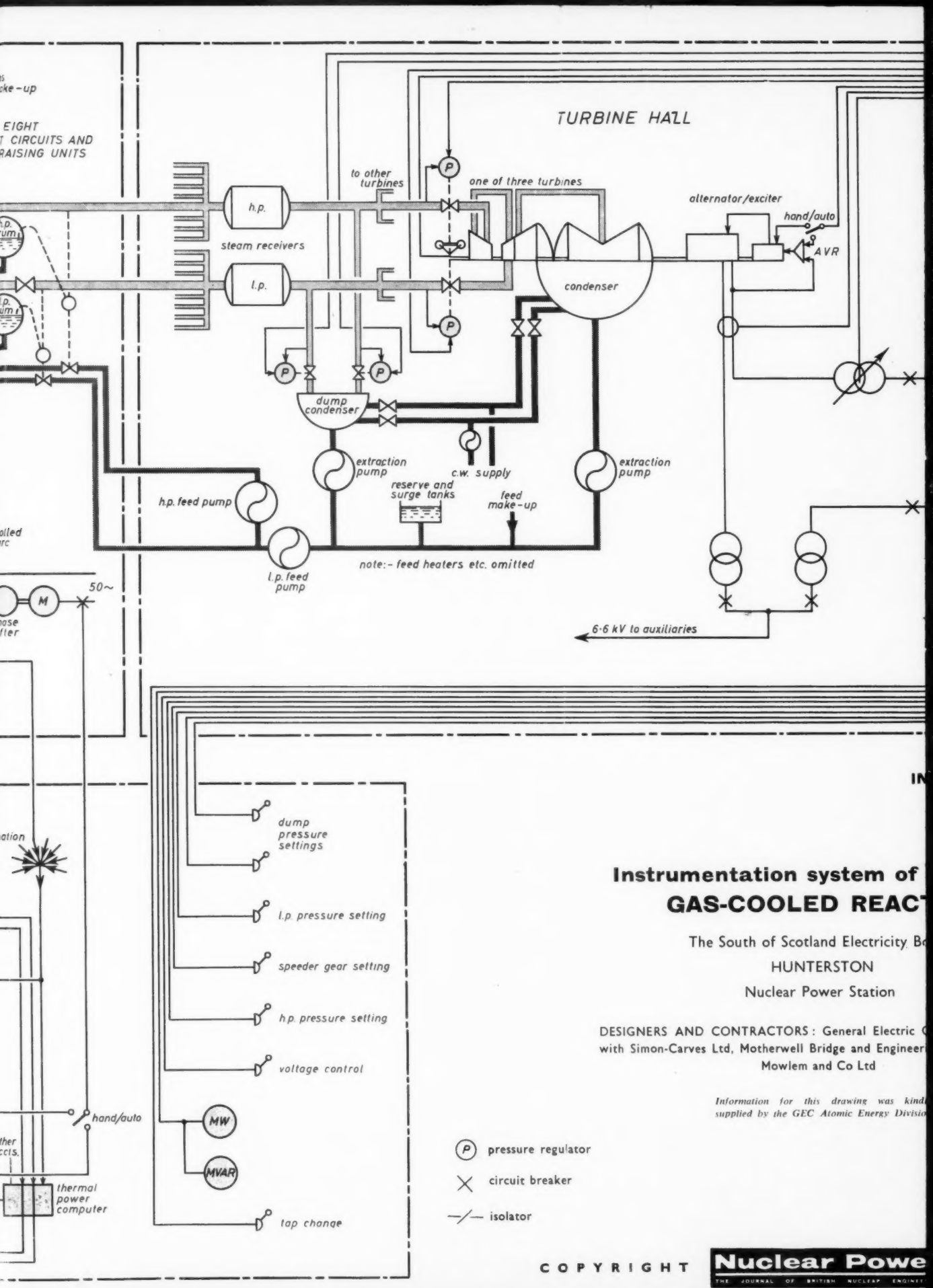
A materials testing reactor

One of the most urgent needs in any full-scale atomic energy programme is the setting up of facilities for testing materials likely to be used in power reactor construction and also the manufacture of isotopes for industry, medicine and agriculture. In Britain we have three powerful test reactors which are used for these purposes. Two of these—PLUTO, illustrated here, at Harwell and DMTR at Dounreay—are identical. DIDO at Harwell is similar but more adapted to fundamental research. All these reactors used highly enriched fuel (over 90 pct pure U-235) in the form of sandwich plates and are both moderated and cooled by heavy water, of which they each use about 10 tons. Since they generate considerable heat (10 MW) positive arrangements have to be made for cooling and the heat in the heavy water is transferred to light water and then dissipated in forced draught cooling towers.

The control system comprises seven signal-arm type combined coarse control and shut-down arms, which are pivoted in the space above the heavy water, a servo-driven vertical rod for fine control, and two-gravity operated safety rods. All pass between the fuel elements and are driven remotely through slave gearboxes from the master gearbox in the control room.

As much of the instrumentation as possible is designed to fail safe and the circuitry involved is based on the so-called 'two out of three' system. Most of the physical instruments—measuring temperature, flow, fluid pressure and level etc—are used as primary elements in alarm and trip circuits of the reactor.


REACTOR
coarse control
fine control
safety control
duct thermocouple
neutron flux detectors
fuel element thermocouple
trip contactors (duplicated)
low frequency – d.c. generators
M
50~
gas make-up
ONE OF EIGHT
COOLANT CIRCUITS A
STEAM RAISING UNIT
h.p. drum
l.p. drum
circulator
coolant flow transducer
d.c. motor
grid controlled mercury arc rectifier
phase shifter
hand trip
gas valve control
hand control (flux)
low level flux recorder
flux recorder
flux calibrate
other trip devices
safety ccts.
one of 3 shut down amplifiers
flow summation
signals from other ducts
mean signal derivation
flux controller (on/off)
hand/auto
desired flux
trimming unit
fuel temp. and flux/flow recorder (2 pen)
set desired power (auto)
power setting unit (gauged potentiometers)
desired total coolant flow
total flow controller (on/off)
from other gas ccts.
flow/flux trim
hand control (flow)
thermal power and coolant flow recorder (2 pen)
coolant temp. recorder (2 pen)
CENTRAL CONTROL ROOM



Instrumentation system of
GAS-COOLED REAC

The South of Scotland Electricity Bo
HUNTERSTON
Nuclear Power Station

DESIGNERS AND CONTRACTORS: General Electric C
with Simon-Carves Ltd, Motherwell Bridge and Engineeri
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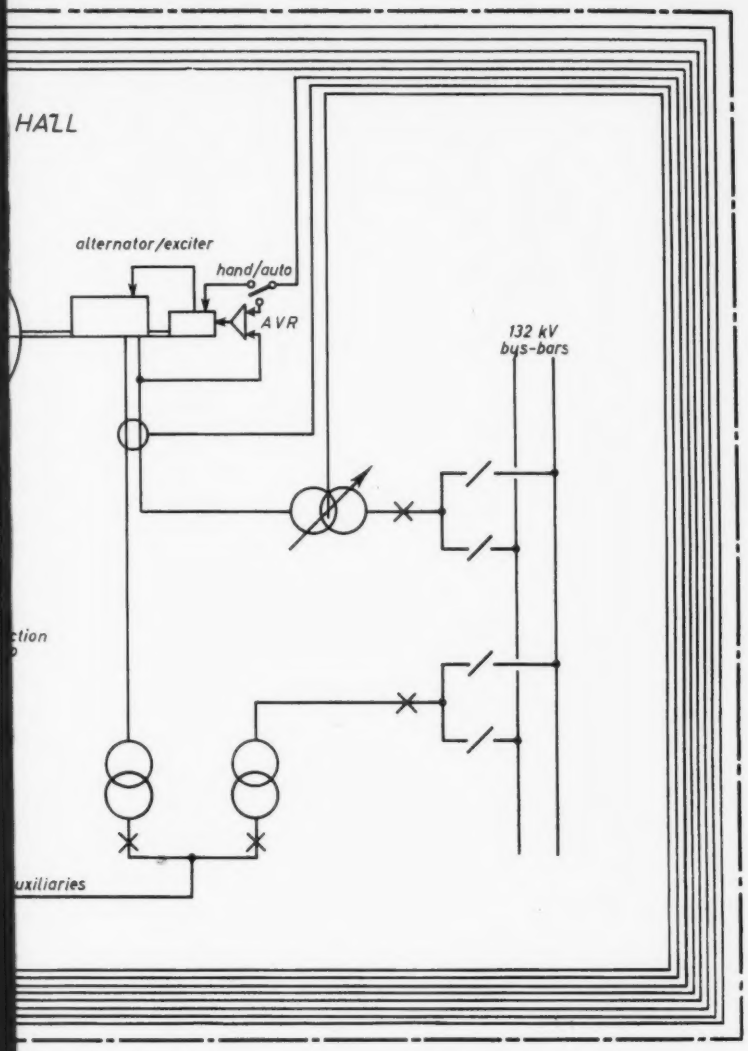

INSTRUMENTATION 1958

trumentation system of a typical GAS-COOLED REACTOR

The South of Scotland Electricity Board

HUNTERSTON

Nuclear Power Station

RS AND CONTRACTORS: General Electric Co Ltd in association
n-Carves Ltd, Motherwell Bridge and Engineering Co Ltd, and John
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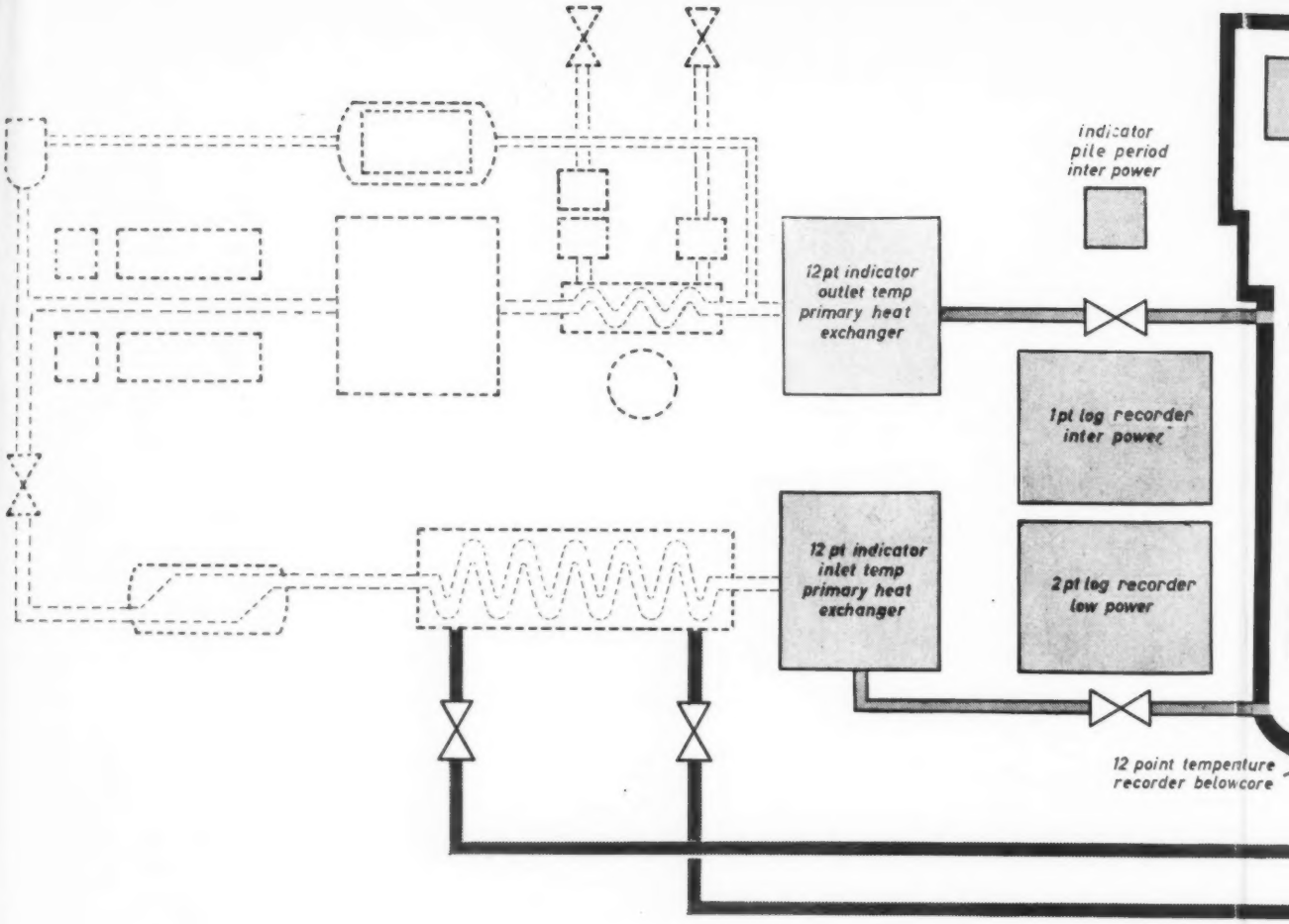
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12pt indicator outlet temp primary heat exchanger
1pt log recorder inter power
12 pt indicator inlet temp primary heat exchanger
2pt log recorder low power
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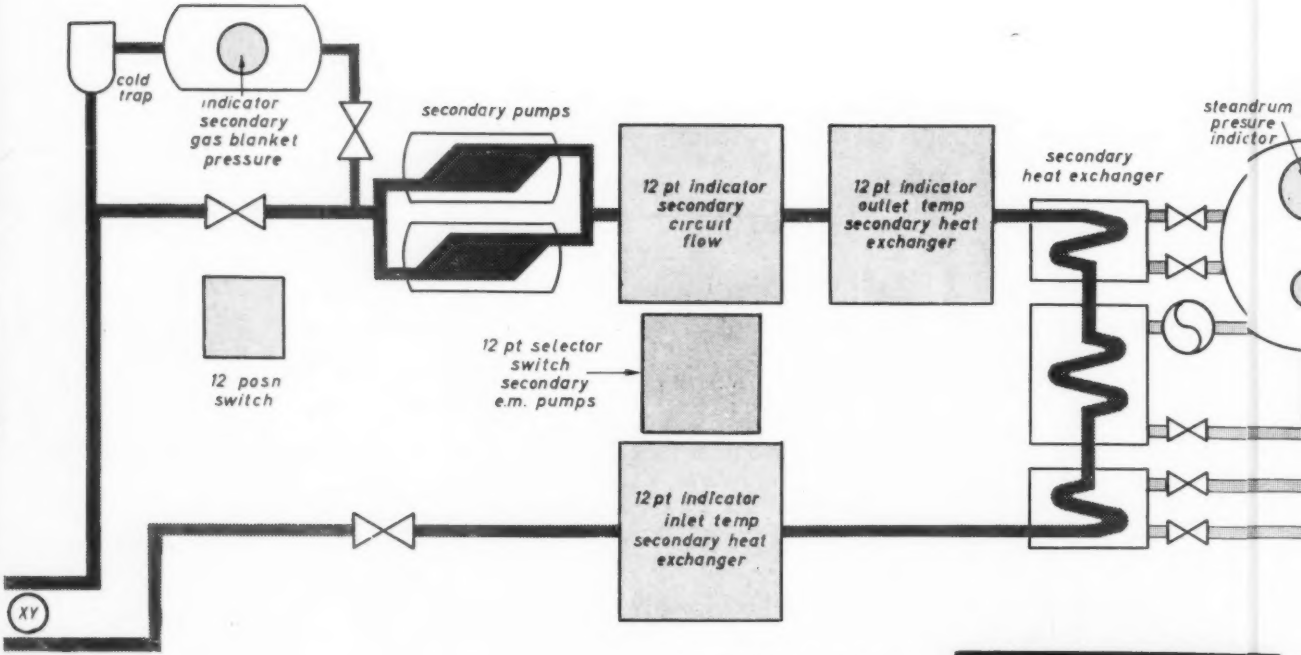
cold trap
indicator secondary gas blanket pressure
secondary pumps
12 pt indicator secondary circuit flow
12 pt indicator outlet temp secondary heat exchanger
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12 posn switch
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12pt indicator inlet temp secondary heat exchanger
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secondary sodium circuit continued

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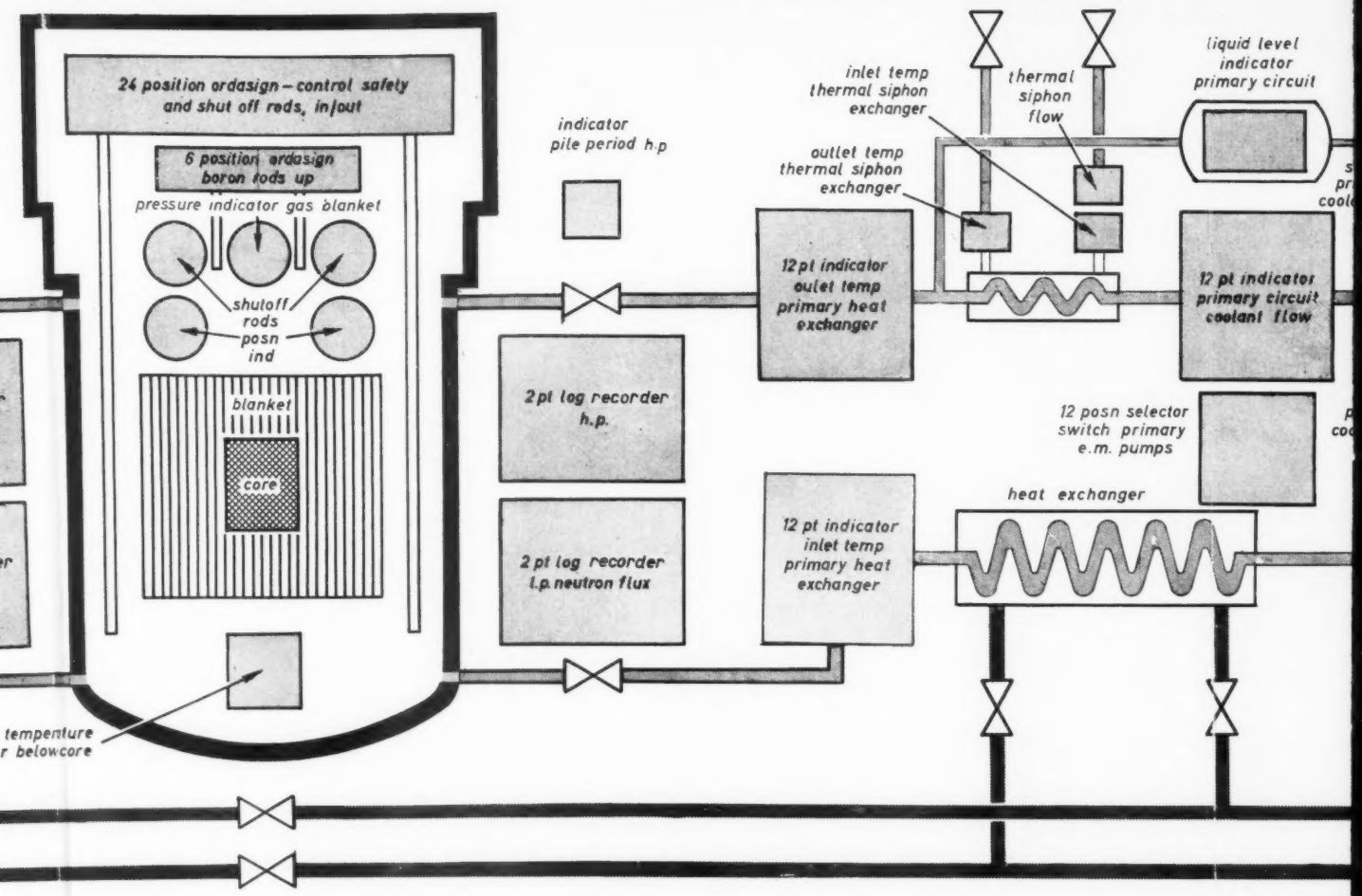
24 position ordasign – control safety and shut off rods, in/out
6 position ordasign boron rods up
pressure indicator gas blanket
shutoff rods posn ind
blanket
core
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indicator pile period h.p
2pt log recorder h.p.
2pt log recorder l.p. neutron flux
inlet temp thermal siphon exchanger
outlet temp thermal siphon exchanger
thermal siphon flow
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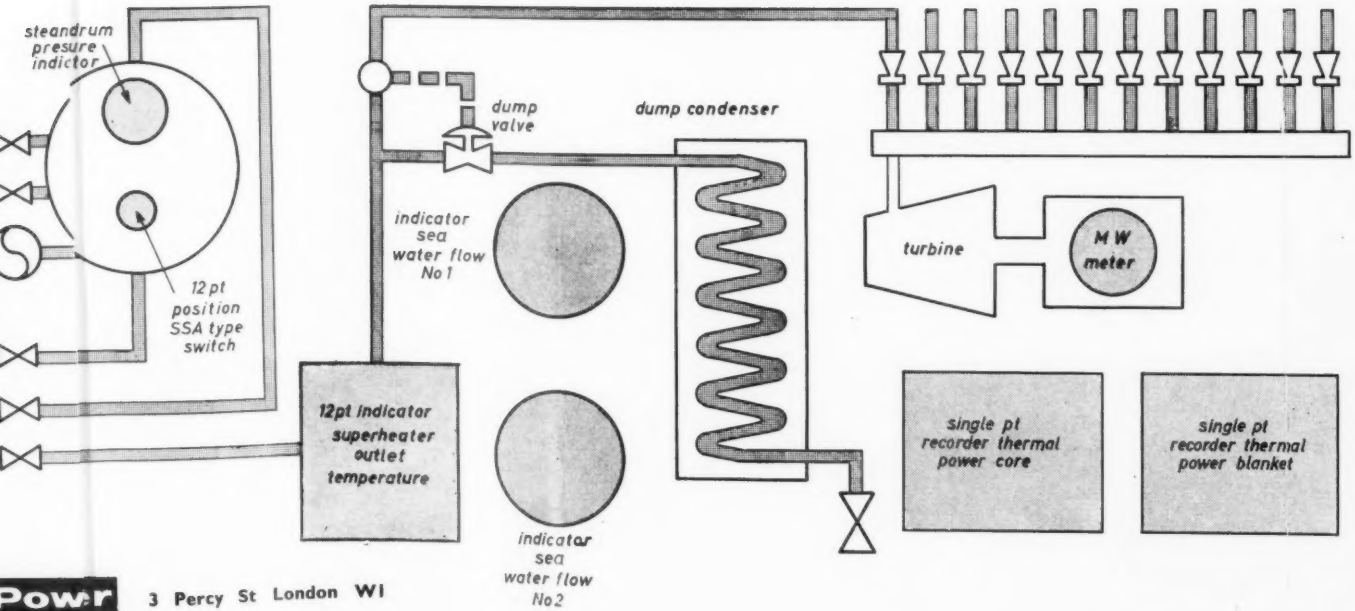
12pt indicator outlet temp primary heat exchanger
12 pt indicator primary circuit coolant flow
12 posn selector switch primary e.m. pumps
heat exchanger
12 pt indicator inlet temp primary heat exchanger


steandrum presure indictor
12pt position SSA type switch
dump valve
dump condenser
indicator sea water flow No 1
turbine
MW meter
12pt indicator superheater outlet temperature
indicator sea water flow No 2
single pt recorder thermal power core
single pt recorder thermal power blanket

Power
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iquid level
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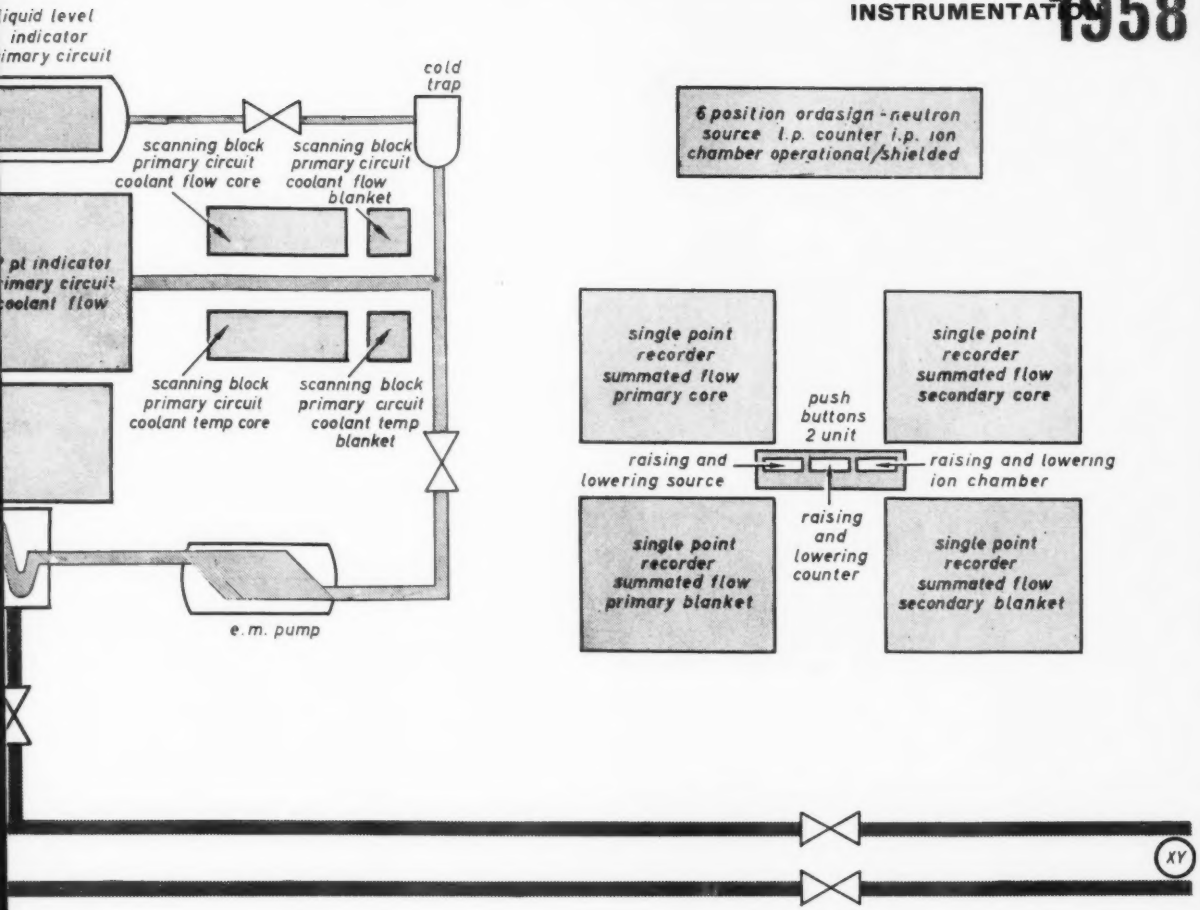
liquid level indicator primary circuit
cold trap
scanning block primary circuit coolant flow core
scanning block primary circuit coolant flow blanket
pt indicator primary circuit coolant flow
scanning block primary circuit coolant temp core
scanning block primary circuit coolant temp blanket
e.m. pump
6 position ordasign - neutron source l.p. counter i.p. ion chamber operational/shielded
single point recorder summated flow primary core
single point recorder summated flow secondary core
push buttons 2 unit
raising and lowering source
raising and lowering ion chamber
raising and lowering counter
single point recorder summated flow primary blanket
single point recorder summated flow secondary blanket
XY

Instrumentation system of a typical

FAST BREEDER REACTOR

The United Kingdom Atomic Energy Authority

DOUNREAY FAST REACTOR

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Instrumentation system of a typical MATERIALS TESTING REACTOR

The Atomic Energy Research Establishment

PLUTO

DESIGNERS AND CONTRACTORS : Head Wrightson Processes Ltd

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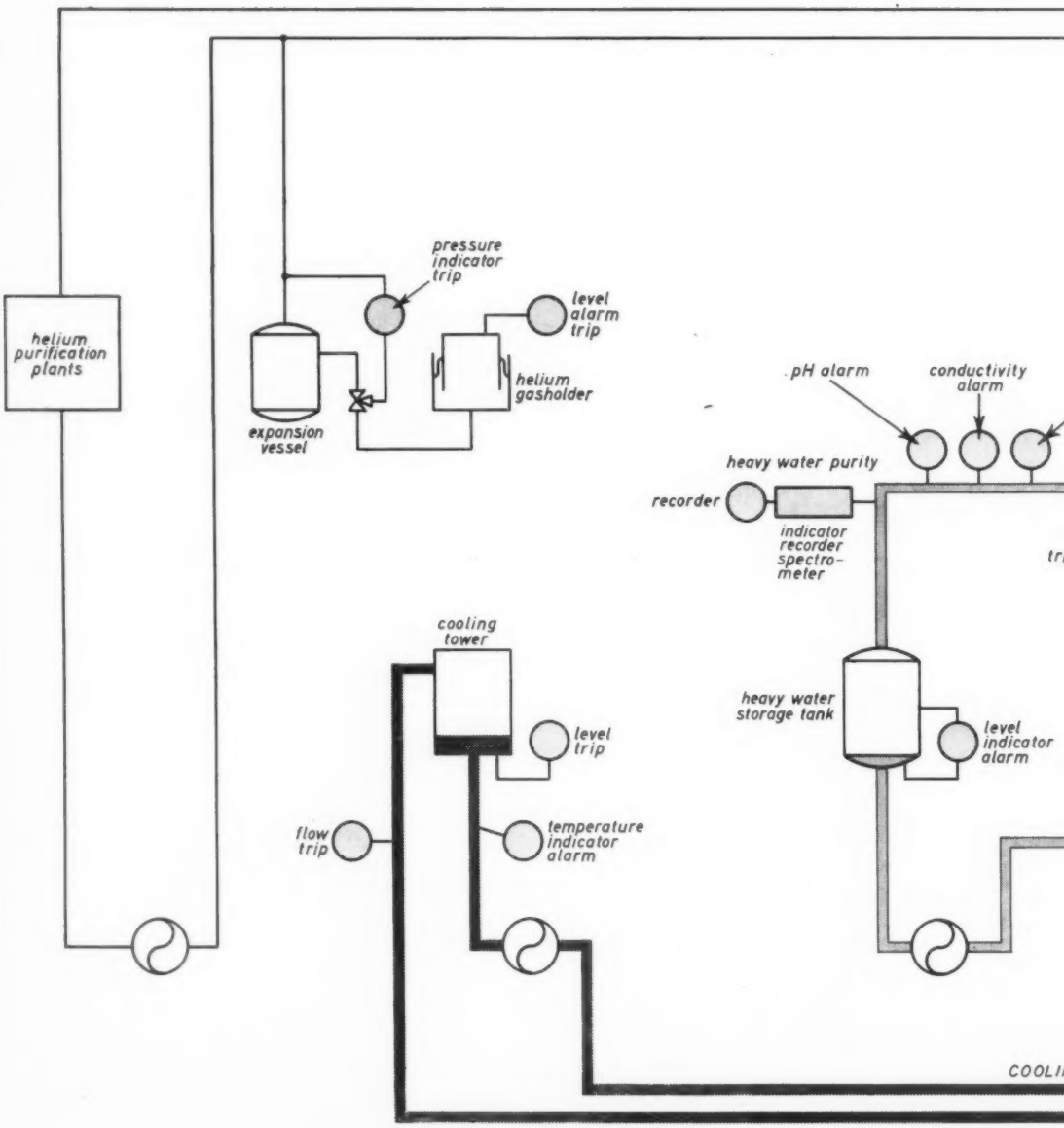

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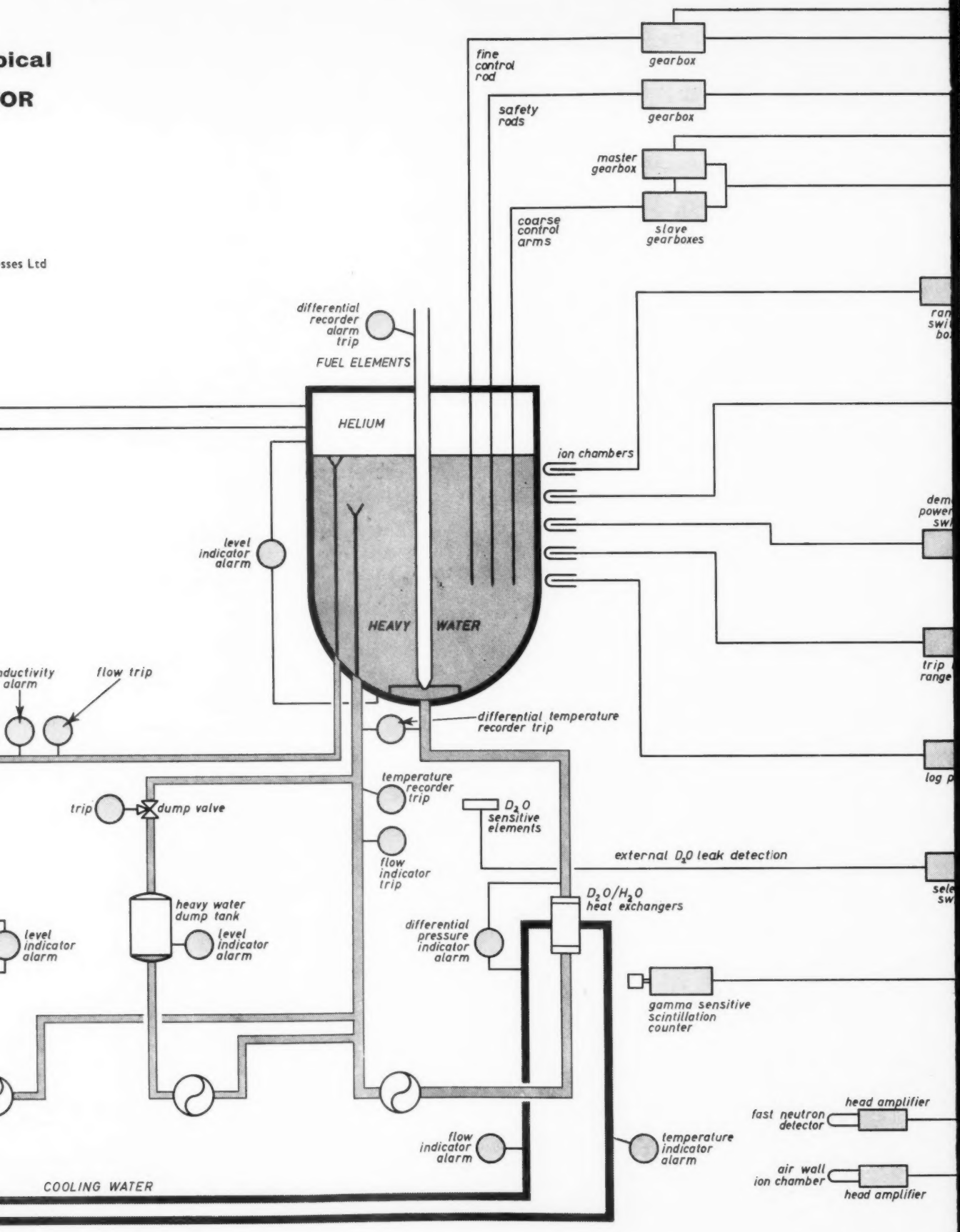
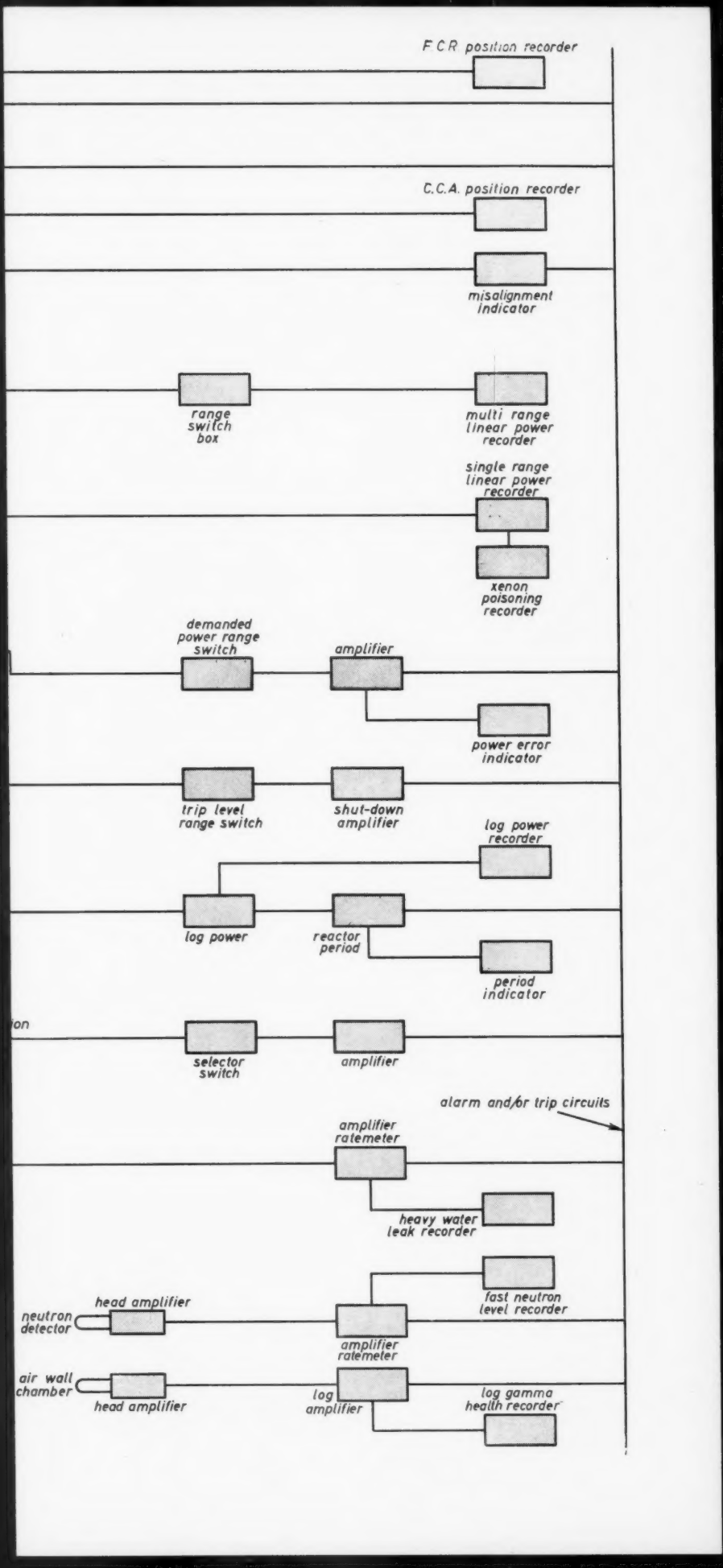
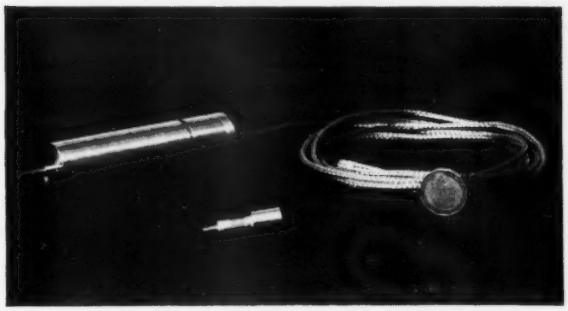



F.C.R. position recorder
C.C.A. position recorder
misalignment indicator
range switch box
multi range linear power recorder
single range linear power recorder
xenon poisoning recorder
demanded power range switch
amplifier
power error indicator
trip level range switch
shut-down amplifier
log power recorder
log power
reactor period
period indicator
selector switch
amplifier
alarm and/or trip circuits
amplifier ratemeter
heavy water leak recorder
fast neutron level recorder
head amplifier
neutron detector
amplifier ratemeter
air wall chamber
head amplifier
log amplifier
log gamma health recorder

by A. L. GRAY, BSc
Plessey Nucleonics Ltd



This experimental flux scanning d.c. ionization chamber for use in gas-cooled reactors is only 1 in. dia. Its flexible cable is stainless steel and quartz fibre. In the foreground is one of the ceramic-to-metal seals used in the chamber

6 MEASURING FLUX DISTRIBUTION IN POWER REACTORS

FOR THE EFFICIENT use of a power reactor as much of the fuel as possible should be run at the upper safe limit of neutron flux and hence, as far as possible, the distribution of flux throughout the core should be uniform. This is usually achieved by rearrangement of the fuel charge at regular intervals as the fuel is depleted, partially depleted elements, or even in extreme cases absorbers, being used in positions where the flux is highest. It is therefore necessary for the operating staff to know the flux distribution within the reactor at any time.

In principle the measurement of this distribution presents little problem as the fluxes are high and a wide variety of methods are available. However, the practical difficulties associated with the high operating temperature and pressure inside the core structure of a power reactor limit the choice of method severely, and several methods which have proved very convenient and straightforward on reasearch reactors cannot be employed. It is thus appropriate at this stage to consider the possible methods and the factors which limit their use.

Different reactor conditions

For the purpose of flux scanning, power reactors may be divided into two main classes requiring different solutions to the problem. The first consists of the gas-cooled natural uranium reactors of the type now being built for the CEGB and SSEB. The core and pressure vessel of reactors of this type are very large and operate at comparatively low pressures of a few hundred psi and temperatures up to 400°C. To insert flux measuring detectors or materials into such cores requires the use of considerable lengths of cable, wire or tube, which in operation is in contact with the coolant since the use of re-entrant thimbles is not usually possible. However, gas locks for the entry into the pressure vessel are quite practicable and sometimes it is also possible to find space within it for a winding mechanism and cable storage. Because of the lengths involved the use of rigid assemblies is not possible.

The second class of reactor includes those types with small core structures of the order of a few feet in length. This group includes pressurized water, liquid-metal and gas-cooled reactors with enriched cores and also heavy water moderated reactors with natural uranium cores. Although these reactors do not necessarily operate at higher temperatures than the first class, they usually involve pressures of up to 2000 psi and it is not therefore desirable to introduce detectors directly into the core. However, since the overall dimensions are comparatively small, re-entrant thimbles leading into the core region are more practicable.

In the power reactors at present proposed the peak flux usually lies between 10^{13} and 10^{14} n/cm^2/sec and it is necessary to make measurements over a range of two or three decades below this. Associated with this neutron flux is a prompt gamma flux which may be as high as 10^7 r/h, and a lower gamma flux due to fission product decay and induced activity in structural materials which is not necessarily distributed in the same way as the neutron flux and which only decays slowly after a reduction of power.

Operational considerations require that the process of flux scanning shall not interfere with the normal functioning of the reactor and under no circumstances can compromise its safety. When a flux scan requires operations on the pile cap, it is preferable that the whole scan can be completed within a normal working shift of 8 hours or less but it is a great advantage if pile cap operations can be avoided. It must be possible to replace any faulty installed equipment while the reactor is running.

Pulse counting techniques

Pulse counters are used extensively in the study of exponential and critical assemblies for flux distribution measurements. The fluxes met in this application, however, are comparatively low. Quite apart from considerations of operating temperature, the peak fluxes in power reactors are far too high for the use of BF_3 proportional counters and are one or two decades above the limit of operation of fission counters because of the effect of pile-up of pulses due to gamma interactions and residual activities.

Where lower fluxes are to be measured, for example

below the normal power range of a reactor during commissioning, the use of a fission counter may be convenient. The problem then becomes one of conveying the information from the counter to the counting equipment. If the core temperature is below 100°C polythene cables may be used, and by using a miniature head amplifier inserted with the counter it is possible to scan the full depth of a large graphite moderated natural uranium core. Where the temperature is greater than this, however, there is as yet no suitable flexible cable that does not introduce spurious pulses, and a rigid extension must be used. This is limited by strength and handling considerations to a length of some 20 ft and the method is only suitable for the smaller enriched cores. A small fission counter suitable for use with polythene cables at low temperatures and at temperatures of a few hundred degrees centigrade with a rigid extension is shown in fig 1. This is suitable for use in fluxes up to about 10^{10} n/cm²/sec and is designed to pass through a $\frac{1}{4}$ in. dia hole so that it may be conveniently inserted into a small thimble.

D.C. ionization chambers

The use of d.c. ionization chambers in the core of a power reactor operating at full power is at present being investigated but the initial results obtained are most promising. By using ceramic insulators and ceramic-to-metal seals, small ion chambers can be constructed which will operate at the temperatures and pressures at present used in gas-cooled reactors and it is reasonable to hope that the upper limits may be much higher than this. The simplest method of use in small enriched cores is again by means of thimbles which avoid contact between the detector and coolant. A small experimental ion chamber

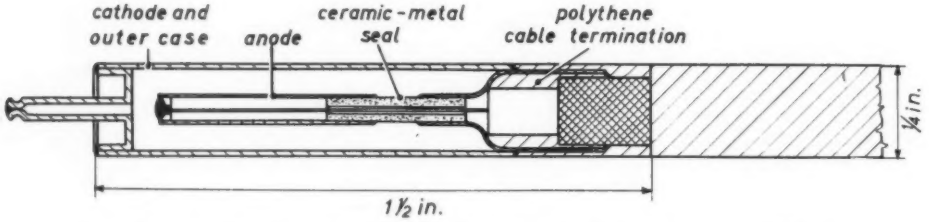


Fig 1 For fairly low flux measurement, fission counters may be conveniently used. This miniature instrument may be inserted into a thimble, preventing contact with the coolant

for this purpose is shown in fig 2. When the electrodes are coated with boron-10 this detector has an output of about 1 milliamp at a flux of 10^{12} n/cm²/sec. The current due to the associated gamma flux in a graphite moderated core is of the order of a microamp. Such a chamber therefore offers a method of measuring neutron fluxes of this order in the presence of the associated gamma fluxes provided that a suitable cable can be found. Since currents of the order of a milliamp are involved, the associated measuring equipment may have a relatively low impedance, of the order of a few thousand ohms. A cable insulation resistance of a few megohms is thus adequate and it must not produce noise currents into the load of more than about 10^{-7} amps. It is probable that a suitable cable for this purpose can be made which will operate satisfactorily at the temperatures required and will still be flexible enough to coil up. A system based on such a detector offers an instantaneous reading of the flux at the position of the ion chamber so that a continuous scan may be performed by lowering the chamber through the core and plotting the output on a recorder. A system of installed scanning heads can then be envisaged across the cap of a large reactor which may be selected in turn to lower their ion chamber into the core and provide a permanent record of the flux distribution in that position in a few minutes. A complete vertical and horizontal scan on two axes might thus be accomplished in a few hours.

Since this may be controlled remotely no interference with operations on the pile cap would be involved. In reactor designs using small enriched cores where higher pressures and corrosive coolants may be employed it is simplest operationally to use thimbles entering the core region so that problems of pressure vessel seals are not involved. The ion chamber may then be used with either flexible leads or rigid evacuated extensions.

Neutron sensitive thermopiles

Some use has been made in research reactors of neutron sensitive thermopiles (*1*) which may be designed to have negligible gamma sensitivities and produce outputs of a few millivolts into a very low impedance. These thermopiles consist of an assembly of thermojunctions in which the hot junctions are coated with some material such as B-10 or U-235 with a large cross-section for thermal neutrons, while the cold junctions are coated with a material of similar gamma absorption cross-section but a very small thermal neutron cross-section. In a neutron flux a temperature difference is thus established between the junctions due to the energy absorption in the high cross-section material, while the system is substantially unaffected by ambient temperature and gamma radiation. The method lends itself to a very simple and robust construction and has been found to operate well in low temperature reactors, but its use in reactors operating at temperatures up to 400°C presents a number of difficulties associated with measuring small temperature differences at high ambient temperatures. A more elegant method is described by Weaver, Smith and Chastain (*2*) in which the temperature difference between elements containing natural and enriched uranium is balanced by electrical heating of the natural uranium element, so that the thermocouple is only used as a null point detector. The electrical power input is then a function of neutron flux independent of the ambient temperature.

Such a system offers considerable promise but has a rather limited range, between one or two decades being achieved with reasonable accuracy for any given detector. It also suffers from the inherent disadvantage of any thermal device, that of a relatively long time constant and it is difficult to see how this could be reduced below a few seconds in a practical device. This would mean, in a large gas cooled reactor, scanning times of the order of 10 minutes to half an hour per channel. It could be installed in the same way as an ion chamber system.

Induced activity methods

The technique of irradiating suitable foils or wires in a neutron flux followed by subsequent determination of

the induced activity is one which is very widely used in nuclear physics research. It is completely insensitive to gamma radiation and capable of a high order of accuracy in suitable conditions. To obtain the distribution along a channel in the core a wire is usually used so that only one insertion is needed per channel. The method has been used on reactors of both classes and has been described by W. Abson and M. Awcock (*3*). In the form developed for the Calder Hall reactors a pure stranded tungsten wire, held taut by a bob weight, is lowered into a special

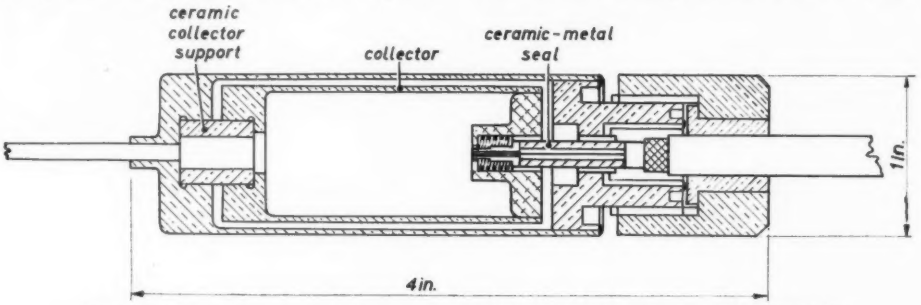


Fig 2 for flux measurement in power reactors, d.c. ionization chambers look promising. The experimental instrument shown here diagrammatically is illustrated p. 171

channel in the core and allowed to remain in this position for about 30 minutes. The wire is lowered by a pressure tight winding head which is fastened in turn to a series of standpipes across the pile cap. After each irradiation period the wire is rewound as quickly as possible and the head transferred to a measuring plinth. The wire is again lowered through the plinth into a mortuary hole. The plinth contains an annular gamma sensitive ionization chamber, the output of which, measured by a d.c. amplifier is proportional to wire activity and hence to the reactor flux at the corresponding channel position. In this way a plot of the vertical distribution in the channel can be obtained. A scan of one channel takes about an hour, but by using more than one head the effective time to do a complete scan of 20 positions across a core may be reduced to about 10 or 12 hours. Apart from involving pile cap operations staff for this period the principal difficulties in the method as applied to large gas cooled reactors lies in the use of tungsten wire. This is the most suitable material from nuclear considerations but does not make a very satisfactory wire. A wire of 19/·0036 strands is used and owing to its brittle nature considerable difficulty with kinking and strand breakage is experienced. However, the system has proved reasonably satisfactory at Calder Hall and similar methods are proposed for a number of the large reactors now being built.

The application of the method to smaller reactors where the wire may not have to be in contact with the coolant presents fewer problems since the choice of wire materials is wider. Nickel wire may be used with a beta sensitive ionization chamber or an annular pulse counter. For small cores the high resolution required is more easily obtained with a beta sensitive detector.

An interesting variant of the induced activity method has been proposed (*4*) in which the beta emission from an irradiated foil is collected and passed to a measuring system. A detector may be constructed consisting of a plate of highly active material separated by a thin insulating medium transparent to beta particles from a second plate of material of lower activity. The net transfer of electrons between the plates constitutes a current which is a measure of the irradiating flux. In practice considerable electrode areas are required and a spiral construction using foils is convenient. The materials used for the electrodes must have short half lives if a short time constant is required, but the low gamma sensitivity and long life possible in a detector of this type are very attractive.

Fission product detection

Instead of measuring induced activity in a foil or wire, fluxes may be determined by measuring the release of fission products from foils of fissionable material. Where the reactor has an installed fission product monitor on the bulk coolant, a rough measurement may be made by inserting a foil of U-235 into the appropriate part of the core and measuring the fission product yield on the monitor. This simple method is however complicated by the varying transit times from various parts of the core to the monitor and may also produce unacceptable contamination of the system. A better method is to introduce the foil to the core within a double re-entrant tube so that a stream of carrier gas can be passed over the foil and the fission products monitored by a separate equipment. This permits the gas flow and transit time to be standardized and avoids contamination of the coolant. It is difficult to accommodate such a system on a large reactor but where a small core permits the use of thimbles the method is reasonably straightforward. The method is, of course, independent of gamma radiation and can be used over a wide range of fluxes.

Choice of system

The choice of a flux scanning system from the methods described above is severely limited by the problems of practical application to a power reactor. In the case of the large gas cooled reactors at present under construction in this country the wire irradiation method has, of course, been shown by experience to be practicable but does suffer from limitations of operational convenience. For reactors of this type the ion chamber method shows the most promise, although its successful application depends on the development of a satisfactory flexible cable.

For smaller reactors the problems involved are usually rather simpler. Since thimbles must usually be used, the problem of connecting a detector to its measuring equipment is simpler and smaller distances are involved. Ion chambers with flexible or rigid leads, balanced thermopiles, wire activity or fission product methods are all feasible and the final choice depends on the precise conditions to be met.

References

1. Jaques, T. A. J., Ballinger, H. A., and Wade, F., 'Neutron detectors for reactor instrumentation.' *Proc IEE* 1953, *100* (Pt 1) No 123, May
2. Weaver, C. V., Smith, C. K., and Chastain, J. W., 'The development of a thermal neutron flux measuring instrument.' *Second Nuclear Engineering and Science Conference*, Philadelphia, 1957, Paper No 57—NESC—39
3. Abson, W., and Awcock, M., 'Two ionization chambers for activity measurements on wires used for neutron flux scanning, *AERE* RIC 2/8
4. Quarmby, R. B., English Electric Co Ltd, private communication

INSTRUMENTATION 1958

7 PHYSICAL SOCIETY EXHIBITION

HORTICULTURAL HALL, WESTMINSTER

MARCH 24—27

This exhibition is an important annual event for the instrumentation industry and, as usual, many new instruments will be on show for the first time. In the next six pages we give a selected preview of the exhibits, with particular emphasis on those interesting to the nuclear industry. Stand numbers are given in brackets after the company's name.

This year NUCLEAR POWER *has been invited to take part. We will be at stand 117 and will be glad to see readers there at any time during the exhibition.*

The exhibition will be open at the following times:

Monday 24:	*10.30*	*to 7*
Tuesday 25:	*10*	*to 9*
Wednesday 26:	*10*	*to 7*
Thursday 27:	*10*	*to 4.30*

Accles & Pollock Ltd (56) Tubes in tantalum, beryllium, vanadium, molybdenum, niobium, zirconium, Zircaloy 2 and titanium are being exhibited. As in previous years there will be samples of seamless stainless flexible tubing, flexible joints and annular convoluted tubes, the helically finned steel tubing usually used as heat exchangers and special thin-walled stainless steel tubing—diameters to 4½in., thicknesses to ·005in. Examples of finned sections for the canning of uranium will be seen, in aluminium, aluminium alloys, niobium and magnesium etc.

Airmec Ltd (3) Oscilloscope (type 249) is a general multi-channel instrument adapted to viewing, comparing and measuring several related wavelengths simultaneously. Special features are both time and voltage calibrations, time base expansion, rigid synchronization and triggered operation. Other equipment being shown includes a wave analyser and an AM/FM modulation meter.

Avo Ltd (29) will show their radiation monitor no 1, a portable, self-calibrating battery-operated instrument measuring X, beta and gamma radiation on a 5in logarithmic scale calibrated from 1 mr/h to 5 r/h. The hot spot monitor is also portable, with a remote ion chamber, for measuring radiation intensity in close proximity to high level sources of beta and gamma radiation. Readings can be obtained from 0·1 r/h to 500 r/h.

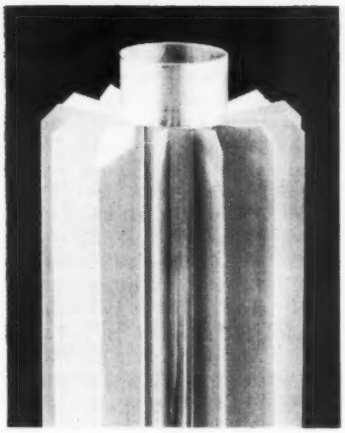
Baird & Tatlock (London) Ltd (113) Among the latest developments in the *Analmatic* range will be the BTL *Analmatic* analyser for automatic analyses of grouped individual samples. It consists of reagent unit, transfer unit and recording absorptiometer. A new instrument for the measurement of concentrations in liquids by colour matching is the BTL titration absorptiometer. It is well suited for dealing with small quantities at a high rate of accuracy.

British Thomson-Houston Co Ltd (31) have a single-phase a.c. conduction pump with combined transformer for laboratory duty. No special supplies are required and, with the use of appropriate tube materials, it can handle mercury, bismuth and the sodium or sodium-potassium alloys. Two sizes can be seen with normal ratings of six gall/min, 15 lb/sq in, and 20 gall/min, 20 lb/sq in. By the use of semi-conducting materials the solid state electroluminescent image converter panel, also on show, can obtain a visible picture from an infra-red one. The instrument consists of large area photo-conducting and electroluminescent layers in series between two transparent conducting electrodes.

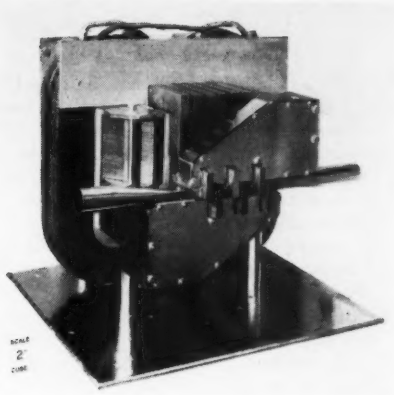
Cambridge Instrument Co Ltd (97) The residual hydrazine recorder is employed with boiler feed plants where hydrazine is used to remove dissolved oxygen from feed water. It consists of an analyser cell through which feed water flows. An electrolyte is fed into it, giving the water a small degree of conductivity. The cell has two electrodes between which a fixed potential is applied, the presence of hydrazine causing a current to flow through the cell, proportional to the hydrazine content. Externally the current passes through a variable resistor, the potential difference being measured by an electronic recorder.

Cawkell, A. E. (105) In type LDA a new and very sensitive non-destructive testing equipment for determining damping constant or 'G' by exciting specimen into vibration is introduced. Can be used on a wide range of engineering materials. There will be two similar items for use with concrete and for quality control.

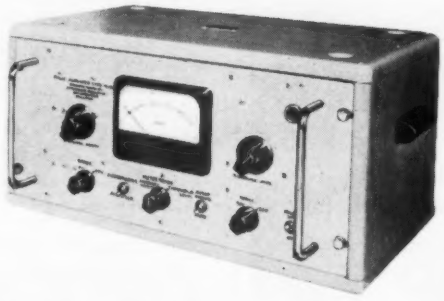
Crystal Structures Ltd (54) The Wooster diffractometer is designed for use with X-rays but could be easily adapted for neutron diffraction. Machine has been automized, using a punched tape and may be programmed to move at predetermined speeds.



ACCLES & POLLOCK—fuel element can



BTH — electromagnetic pump



DYNATRON—pulse analyser

EKCO—autostandardization gauge

Dawe Instruments Ltd (103) will be showing ultrasonic cleaning equipment (type 1150). Cleaning results from the rapid formation and collapse of vapour bubbles within an electronically excited corrosive liquid. The newly-developed rectangular tank and transducer assembly has a two gallon capacity, and the stainless steel immersible bulkhead transducer units allow easy introduction of ultrasonic cleaning into existing baths. Among cleaning problems solved by this method are radioactive soil, ball and roller bearings.

Dynatron Radio Ltd (34) have a new single channel scanning pulse analyser (type N102) for use in gamma spectrometry. It comprises a fast threshold amplifier followed by two discriminators and gives an output pulse when only the lower discriminator is triggered. The threshold can be scanned while the channel width remains fixed at a value which can be set between 0 and 50V. The analyser's output can be fed either to a scaler or a ratemeter. If the latter is used a continuous spectrum record can be obtained by transferring the ratemeter output to a chart recorder.

Edwards High Vacuum Ltd (107) will be showing an ultra high vacuum pumping system demonstrating an all metal shut-off valve, closed conductance of 10^{-10} litres per second, bakeable to 450°C and an ionization gauge measuring pressures down to 10^{-10}mm Hg and bakeable to 450°C, sensitive d.c. amplifier with an electrometer valve as first amplification stage, and a simpler seven range d.c. amplifier, measuring down to $2{\cdot}5 \times 10^{-11}$ amp corresponding to a pressure of $1{\cdot}25 \times 10^{-10}$mm/Hg. Among other interesting items special note should be taken of an ultrasensitive ionization gauge control unit in six ranges covering 10^{-2} to 10^{-7}mm/Hg f.s.d.

Ekco Electronics Ltd (24) are showing a new gamma backscatter gauge (type N563) designed to measure steel thicknesses where only one side is accessible. Transistors and printed circuit techniques are employed and the unit is operated either by battery or power unit. The type N582 autostandardization gauge has a retractable scanner, automatically withdrawn from the sheet at half-hourly intervals to carry out tests to correct errors due to source decay, contamination, etc.—introduced since the previous standardization. A new beta scintillation counter (type N612) will be demonstrated with a N530 scaler. Developed for counting low energy beta particles, it is especially useful for assaying carbon-14 and tritium.

Electronic Tubes Ltd (39) Improvements have been made to this well-known range of cathode ray tubes which now incorporate improved gun construction to reduce electrical tolerances.

Elliott Bros (London) Ltd (106) The 402F floating-point digital computer will be demonstrated. The machine, an addition to the 400 series, consists of a 402E fixed-point computer with three extra cabinets and works under programme control in either fixed or floating point mode. The floating-point unit deals with numbers in the range 2^{-30} to 2^{+31} with sign, numbers outside that range being treated as zero and infinity. A production model of the general purpose analogue computer *G-PAC* can be seen together with a wide display of non-linear units and accessories. A reactor simulator (type ND181) has been designed to represent the operation of a nuclear reactor under varying conditions. The unit is in the form of a reactor control desk with indicators showing power level, control and safety rod position etc. Pile parameters representing various constants dependent on fuel and moderator can be chosen by the operator to simulate different types of reactors.

EMI Electronics Ltd (16) show a hand and clothing monitor. Both sides of the two hands are monitored simultaneously for alpha and beta contamination by means of four scintillation counters. The alpha clothing probe is a scintillation counter feeding a logarithmic ratemeter while the beta-gamma probe uses a halogen quenched g.m. tube. A complete electronic analogue of a chemical plant will also be shown. This computer gives detailed study of plant operating characteristics and a new approach to plant design. The plant simulated forms a closed loop and is made up from three kinds of unit—storage tanks, operating column and connecting pipes with their associated pumps.

Engelhard Industries Ltd (Baker Platinum Div) (78) The exhibition model of the Hersch dissolved oxygen meter to be shown employs the same galvanic principle for the measurement of oxygen successfully used in the Hersch oxygen meter. The instrument operates in two ranges, the most sensitive covering the boiler feed water application of 0–0·025 ppm. Water flow is 15 lph and speed of response approximately two minutes.

English Electric Valve Co Ltd (30) are exhibiting their extensive range of valves including a new high vacuum rectifier rated at 65 kV peak inverse.

Ericsson Telephones Ltd (13) counting equipment (type 127A) is designed for a fast and reliable nucleonic count rate. The complete equipment comprises preamplifier quench unit, e.h.t unit, amplifier discriminator, high speed scaling unit, logarithmic and linear ratemeters and timing unit. With the exception of the first two items these instruments can be rack mounted in a steel cabinet. Also shown will be the survey meter (type 125A), a lightweight portable instrument for geological surveying and prospecting of radioactive ores. Size is 7¼in. by 3½in. by 1¾in. and total weight 1½ lb. Using hearing aid batteries, the instrument operates for 120 hours without battery change. Accuracy of calibration is maintained over battery range 4·5 to 3V.

Ferranti Ltd (25) will exhibit a range of cathode ray tubes producing radar displays bright enough for viewing under high ambient lighting conditions.

Fleming Radio (Developments) Ltd (6) Developed in collaboration with the UKAEA is the millimicrosecond pulse shaper (type 1530A) to be shown here. It is designed to speed up the leading edge of the pulses from Fleming's pulse generator (type 1147B). Positive pulses are fed through 100 ohm coaxial cable to the shaper which then delivers two negative output pulses of 1 millimicrosecond rise time and 7 volt amplitude into 70 ohm matched coaxial cables. Also on this stand will be a portable pulse echo fault locator for use on power transmission lines over distances up to 200 miles.

Furzehill Laboratories Ltd (37) have an entirely new precision RC oscillator with an incremental control. The control acts as a fine tune and provides a constant frequency increment of the main dial's setting.

Gallenkamp & Co Ltd. A (69) are showing a new line of ovens and incubators.

General Electric Co Ltd (23) are exhibiting an extensive range of valves, cathode ray tubes etc.

GEC Research Laboratories (22) will have on show apparatus for investigating dynamic properties of a.c. discharge and for differential thermal analysis of chemical reactions in glass and refractory production. Semi-conductors, high expansion glasses, a radiation pyrometer and highly loaded low-pressure fluorescent tubes can also be seen.

DON'T MISS THESE

- **hot spot monitor**
  Avo Ltd
- **new beta scintillation counter**
  Ekco Electronics
- **nucleonic counting equipment**
  Ericsson Telephones
- **new non-destructive tester**
  A. E. Cawkell
- **millimicrosecond pulse shaper**
  Fleming Radio

Griffin & George Ltd (57) will exhibit two recently developed instruments. The VPC apparatus Mk II is for analysis at reduced pressure of mixtures having components with boiling points to 350°C at atmospheric pressure. It has two ovens, an independently controlled thermostat and a motor-driven fan for air-convection. The BCRA isothermal bomb calorimeter is embodied within a bench with all controls in easy reach. The jacket is isometrically controlled.

Hilger & Watts Ltd (92) have a new double-beam polarizer for the H800 infra-red spectrophotometer. It uses selenium films in transmission which act as plane polarizers when the incident beam is inclined at the Brewster angle. Mounted in a cylindrical tube, films are oval—about 10 cm by 5 cm—and about 4 microns thick. The new integrator for the H800 spectrometer measures the charted area of an infra-red absorption band.

Isotope Developments Ltd (15) The 700 scintillation counter head to be shown is completely shielded with the exception of an opening to which interchangeable collimators can be fitted. These allow location of radioactive deposits in the human body or general measurement of uptake and body background. Facilities exist for measuring 10ml liquid samples. The head is available with built-in amplifier, to suit existing scalers and ratemeters, or direct output. Also on view will be the portable scintillation ratemeter (type 1413A), a sensitive gamma detector primarily for uranium prospecting. It consists of a scintillation counter with e.h.t. supply and ratemeter, all of which operate on transistors powered by three ordinary torch batteries.

Johnson, Matthey & Co Ltd (80) Mallory 1000 is a machineable tungsten-base alloy with specific gravity of 16·9. Compared with lead it has 50 pct higher density, superior heat and corrosion resistance, greater mechanical strength and is machineable to close limits. It is relatively resistant to corrosion and can be silver-brazed without difficulty. It absorbs gamma radiation and is ideal for radiation screening.

Kelvin & Hughes Ltd (75) The drift-corrected d.c. amplifier has been developed from a BSIRA basic design and is entered as a research exhibit. By using a system of motor driven contacts with a switching frequency of 5 per sec the input stages are almost completely free from long-period zero drift and the principle of 'cascade-balance' is also employed.

Labgear Ltd (102) Industrial scintillation counter (D4132), shown last year as a prototype, is now in production, and has proved successful for the industrial assay of gamma emitters. Counter head is compact, light and robust; photo tube assembly is spring mounted as an anti-shock measure. Also on show will be a prototype 4 π proportional counter for measurement in methane of low energy beta and alpha emission. Unit is constructed from *Dural* with p.t.f.e. insulators and the chamber is highly polished to avoid turbulence and scattering effects. The counter hinges open in two halves for insertion of the source; its base contains a cathode follower and incorporates an e.h.t. switching device which breaks the supply when the counter is opened.

Lintronic Ltd (41) The linear constant temperature hot-film anemometer records and measures the mean and turbulent velocity of gas or water. The wedge end of a glass rod is coated with a platinum film, which acts as a sensing element, and is mounted in the flow medium. This film is heated to a predetermined tem-

perature and when gas or water flows over it the film is cooled but an electronic feedback system acts to keep the temperature constant. The increase in heating current measures the velocity over the film. Velocity range in the gas is 5-1500 fps and in water 1-60 fps.

Megatron Ltd (7) will show their range of mounted and unmounted selenium photocells with varying spectral characteristics. Also of interest is the selenium photocell transistor unit. The two pin unit can be plugged to standard sockets and is suited to photo-electric relay work, counters etc.

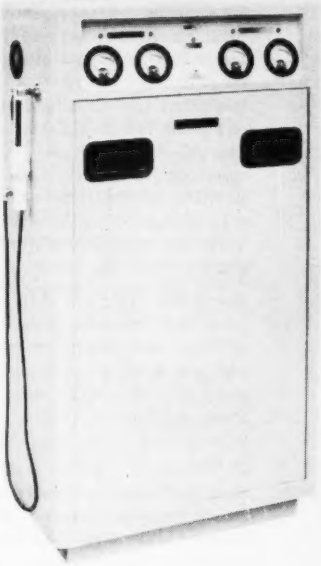
Mervyn Instruments (76) The latest model of the NPL infra-red spectrometer incorporates curved slits and has a resolution better than $1cm^{-1}$. The instrument uses a Merton-NPL grating, F-centre crystal filters and interchangeable photoconductive detectors. The slits can easily be adjusted by the micrometer which is located in the monochromometer compartment. The large area alpha scintillation counter is designed for samples of low activity and is claimed to have twice the scanned area of other counters. A 3in. dia sample holder is incorporated, there is an extremely low background count rate and the instrument is strongly built for field work.

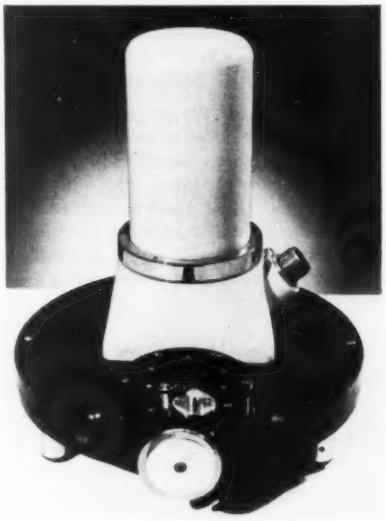
Metropolitan-Vickers Electrical Co Ltd (72) The MS6L mass spectrometer shown here is designed as a portable instrument for leak detection. It has high sensitivity, gives a direct measure of concentration and is positive in indication. It can be used for testing pressurized or evacuated systems, for detecting and locating leaks and measuring the rate of leakage. The instrument is connected directly to vacuum systems and the tracer gas applied to the exterior either by probing or placing an envelope around the whole or part of the system. Pressure vessels are tested by introducing tracer gas under pressure to the inside and sampling the atmosphere around suspect areas. This spectrometer is completely self-contained. Sensitivity is better than 1 in 500,000 parts for helium in air.

Muirhead & Co Ltd (89) Amongst the exhibits will be a D-901 facsimile transmitter and D-900 facsimile recorder. These machines give fully automatic transmission of information and data over the normal telephone system. The transmitter accepts all forms of printed matter, typescript, hand-written text, drawings etc, which are exactly reproduced by the recorder.

Mullard Ltd (104) will show a full range of radiation detector tubes, including halogen-quenched geiger-müller tubes and a newly-developed proportional counter for the measurement of CuK

EMI—hand and clothing monitor

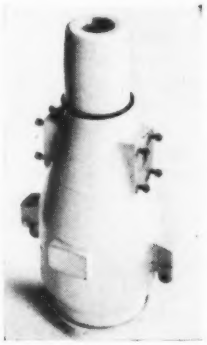




MERVYN—alpha scintillation counter

METRO-VICK—mass spectrometer

ISOTOPE DEVELOPMENTS—counter head



radiation. Research instruments to be demonstrated will include a high resolution nuclear magnetic resonance magnet and associated equipment to observe and record high resolution nuclear magnetic resonance spectra of the proton. A new hand and clothing monitor on view has been designed in consultation with Harwell for rapid use by skilled and unskilled personnel. Unit construction provides versatility in both number and type of monitoring facilities and there is automatic subtraction of gamma background.

Murex Ltd (110) will display their fabricated molybdenum, tungsten, tantalum, niobium and zirconium products. Included are items of chemical plant fabricated in tantalum by seam welding and argon arc fusion welding. For the first time reactor grade zirconium sheet will be seen.

Nash & Thompson Ltd (9) have new additions to their range of plastic scintillators. Also on view will be examples of canned and tested sodium iodide crystals and a computer unit.

Panax Equipment Ltd (44) A new universal scintillator castle gives 1½in. lead protection all around the scintillation detector and photomultiplier tube. Samples are introduced to the castle on a carrying slide. The castle is light-tight and an e.h.t. interlocking switch safeguards the photomultiplier tube in applications where the detector is not encapsulated. The castle may be inverted so that a flexible instrument is available for a wide variety of applications, including gamma ray emitters, liquid scintillators for soft beta ray emitters and moderate energy beta and soft gamma emitters.

Philips Electrical Ltd (108) Electronic circuit panel (PW1051) supplies a highly stabilized source of e.h.t. for various types of radiation detectors. The e.h.t. can be varied from 700 to 2000V by coarse and fine controls with stability of ± 0·1 pct over an eight hour period. The panel contains the scaling circuits with provision for both 'fixed count' and 'fixed time' operation with a resolution time of 1 microsec. Ratemeter facilities are available with a 10in. recorder showing the final trace on a roll chart providing 27 ranges from 30 to 12,800 cps for full scale deflexion.

Planer Ltd, G. V. (5) A range of oxide and metal film type potentiometers.

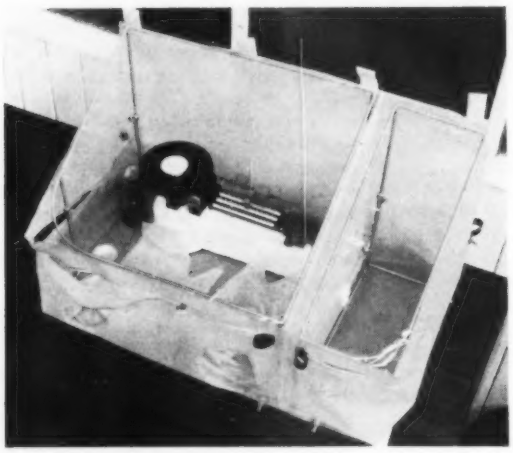
Plessey Co Ltd (19) Exhibits include cermets, square loop ferrites, intermetallic semi-conductors, thermistors, transistors and silicon rectifiers and electrolytic capacitors. Other features will be magnetostrictive and microwave ferrites, the former particularly suited to medium power ultrasonic generation, and a single crystal memory store produced by evaporating or printing electrode systems on to a single crystal of barium titanate.

Pye & Co Ltd, W. G. (99) Gas-liquid chromatography apparatus (11880) is a new instrument of high resolution and extreme sensitivity. It will take up to four metres of column, although for most analyses a single meter column of 3000 plates is more than adequate to separate sample components. A katharometer is used as a detector, the overall sensitivity of the system being improved by means of a low noise d.c. amplifier connected between the katharometer bridge and the recorder.

Rank Cintel Ltd (98) On show for the first time will be a microsecond chronometer, a fully transistorized portable unit for measuring time in the range 1 microsec to 1 sec in steps of 1 microsec with very high accuracy. Also new is a universal counter/timer, transistorized and portable, and a range of printed circuit counter panels.

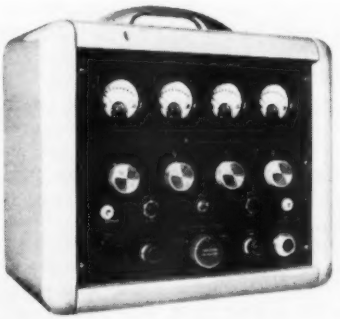
Sanders (Electronics) Ltd, W. H. (2) The type LF3 oscilloscope has been developed to meet the requirements of industrial control equipment.

Servomex Controls Ltd (43) are showing a random signal generator for testing non-linear control systems. Also seen will be a fully transistorized regulated d.c. supply.



TOWNSON & MERCER—flexible glove cabinet

VENNER — transistorized batching counter



PANAX—scintillator castle

TEXAS INSTRUMENTS—high power transistor (actual size)

Shackman & Sons, D. (66) will have on show a selection of automatic recording cameras and accessories for photographing equipment panels, oscilloscope traces, etc. The oscilloscope recording cameras (types AC2/25 and AC2/50) are specially designed for photographic recording of oscillograph traces using both shot-by-shot and continuously moving film methods.

Solartron Electronic Group Ltd (96) The CD643 *Solarscope* has been developed as a measuring oscilloscope as well as a display unit. The signal input circuiting incorporates a time delay and both amplitude and time measurement are plus or minus 2 pct.

Solus-Schall Ltd (28) X-ray diffractometer (50200) with its associated electronic ratemeter amplifier chart recorder etc. is used to determine the position, intensity and width of diffraction lines from poly or single crystals in the plane of motion of the counter tube. The instrument is also suitable for other uses such as X-ray fluorescence and chemical analysis. The electronic fast counting ratemeter/amplifier (50211) is used for X-ray diffractometry. It incorporates a stabilized e.h.t. supply, variable gain control, discriminator, cathode follower output circuit for a scaler and ratemeter ranges from 0 to 100,000 pulses per second. Also on show will be an ultrasonic flaw detector and a range of radioisotope containers.

Southern Instruments Ltd (11) The *Magna-Gage* electronic gauge with its accessories provides a versatile equipment for semi- or fully-automatic indication and control of dimension tolerances. Electrical impulses are carried by cable to a remote indicating unit which shows tolerance limits by coloured light signals. Relay outputs are available from this unit for automatic sorting or machine control.

Texas Instruments Ltd (40) will be showing their line of silicon diodes and transistors. Main exhibits, using a high power transistor, will be a remote position control servo system, a torque relay and a d.c. converter.

Thermal Syndicate Ltd, The (63) will show a new type of fused silica. Known as synthetic fused silica, it is made from pure silicon compounds instead of quartz crystal. Its impurity content is less than one part in a million.

Thompson Ltd, J. Langham (32) have a new frequency meter (type 1795), designed also as a tachometer, ratiometer or time interval meter, using a neon figure display readable at 20 ft.

Tinsley & Co Ltd, H (94) Now in production is the hot wire anemometer (type 5328). Heater wire and butt-welded thermocouple are enclosed in a twin bore silicon tube and a hemispherical shield is employed. Speeds up to 60 ft per second can be measured. The network analyser unit (type 1532B) to be shown comprises the measuring and feedback parts of a transient response analyser for a.c. networks.

DON'T MISS THESE

- **reactor simulator**
  Elliott Bros
- **radiation screening**
  Johnson, Matthey & Co
- **industrial scintillation counter**
  Labgear
- **reactor grade zirconium sheet**
  Murex
- **new hand and clothing monitor**
  Mullard

Towers & Co Ltd, J. W. (64) are showing their series of balances and scientific instruments.

Townson & Mercer Ltd (67) The flexible glove cabinet for handling materials has been modified since it was shown in 1957. It can now be used with either positive pressure, using inert gas or dust free air, or by an inserted metal framework, it can be held to shape while operated with a slight negative pressure. The working area can be opened by an air-tight zip fastener and an air-lock is incorporated into the side. The entire cabinet is of flexible p.v.c., including the gloves which are welded to the structure.

20th Century Electronics Ltd (8) In the travelling wave deflexion cathode ray tube on this stand a pair of travelling wave deflecting systems are arranged for symmetrical deflection of the electron beam on one axis. Conventional deflecting plates are used on the other axis. Signal inputs are applied to both systems through coaxial connectors which are also provided for external termination of the T.W. plates or for feed of the undistorted signal to other equipment. Focus is electromagnetic and post deflexion acceleration is applied up to 20kV.

Unicam Instruments Ltd (100) The flame spectrometer (SP900) exhibited here consists of a propane or acetylene burner fed by an air supply in which the sample material has been finely dispersed by a concentric jet atomizer. Light from the burner is passed through a silica prism monochromator and on to a detector via a 100c/s chopper. The detector output is amplified and rectified and the resulting signal is shown on a spot galvanometer as a direct reading of emission line intensity.

United Kingdom Atomic Energy Authority (109) will exhibit recently developed scientific equipment including a particle size recorder, model production workshop for radioactive materials and a nuclear reactor transfer function analyser.

Venner Electronics Ltd (58) will have a batching counter (type TBC), containing four decades, each being controlled by a 10 position switch calibrated from 0 to 9. A number is set up on the counter and input pulse rates varying from 1 to 10k.p.p.s. are injected, the counter stopping after the required batch is reached. In addition to straightforward industrial applications, it may be used for providing precise delays.

Wray (Optical Works) Ltd (82) The new tank inspection lamp consists of a periscopic system of unit power giving an angle of field of 60 degrees for any one position of a right-angle prism. The prism itself can be revolved through an angle of 75 degrees by means of a rotary sleeve below the eyepiece. Illumination is provided by a low voltage lamp.

ALSO SHOWING

Baker of Holborn, C., 93; British Physical Laboratories, 101; British Scientific Instrument Research Association, 111; Burndept Ltd, 12; Chance-Pilkington Optical Works, Pilkington Brothers Ltd, 61; Cooke, Troughton & Simms Ltd, 84; Cossor Instruments Ltd, 17; Dobbie McInnes (Electronics) Ltd, 35; Doran Instrument Co Ltd, 68; Durham University, King's College, Newcastle-on-Tyne, 114; Electronic Instruments Ltd, 73; Evans Electroselenium Ltd, 46; Fortiphone Ltd, 45; Glass Developments Ltd, 55; Guy's Hospital Medical School, 48; Hatfield Instruments Ltd, 70; Infra-Red Development Co Ltd, 62; Institute of Physics, 118; King's College, London University, 50; Liverpool University, Nuclear Physics Research Laboratory, 53; Locarte Co, 4; McArthur Microscopes Ltd, 79; Medical Research Council, National Institute for Medical Research, 51; Ministry of Supply, 1; Morgan Crucible Co Ltd, 36; Nagard Ltd, 14; National Coal Board, 10; National Institute of Agricultural Engineering, 71; National Physical Laboratory, 20; National Research Development Corporation, 52; L. Oertling Ltd, 88; Optica United Kingdom Ltd, 59; Optical Works Ltd, 83; Physical Society Colour Group, 26; W. R. Prior & Co Ltd, 91; Royal Meteorological Society, 119; Royal Naval Scientific Service, 112; St. Thomas's Hospital Medical School, 47; Salford Electrical Instruments Ltd, 21; Science Museum, 65; Shell Research Ltd, 77; Siemens Edison Swan Ltd, 27; Singer Instrument Co Ltd, 60; W. F. Stanley & Co Ltd, 95; Stanton Instruments Ltd, 87; Techne (Cambridge) Ltd, 38; Tintometer Ltd, 90; Ultrasonoscope Co (London) Ltd, 55; University of Southampton, 49; Vinten Ltd, W., 86; Wayne Kerr Laboratories Ltd, 18.

8 INSTRUMENTS, ELECTRONICS AND AUTOMATION EXHIBITION

OLYMPIA APRIL 16-25

Many overseas firms are among those taking part in this second IEA exhibition to be held at Olympia this month. This preview describes a number of the home exhibits most likely to interest the readers of NUCLEAR POWER.

Open daily, including Saturday, from 10 a.m. to 6 p.m. and until 9 p.m. on Friday 18 and Wednesday 23. Tickets will be available at the door.

A conference will be held concurrently with the exhibition. Admission tickets for the lectures and discussions will be obtainable from the information bureau at the exhibition. Subjects will include progress in the international geophysical year by Dr G. E. R. Deacon, thermonuclear development by S. Kaufman of AEI and a paper 'Computers-Numerical Automation' by Dr A. D. Booth of Birkbeck College

Accurate Recording Instrument Co Ltd (424) will show a range of temperature and pressure instruments including differential pressure gauges and Bourdon tubes. Instruments for local and distance reading will be on view.

Advance Components Ltd (608) will show a new l.f. signal generator.

Airmec Ltd (406). A new battery-operated portable radiation monitor will be exhibited. Main purpose is for checking radioactive contamination but can also accurately determine intensity of alpha, beta or gamma radiation. Counts up to 5000 per sec in four ranges.

W. & T. Avery Ltd (310). Weight control by punched cards will be demonstrated.

Avo Ltd (610) will show a magnetic-mercury scaling unit and various radiation monitors.

Bailey Meters and Controls Ltd (513) will show transistorized on/off controller and alarm unit. Produced for service on nuclear reactors it operates on input signals obtained from thermocouple units and has no mechanical moving parts except final relays, which are hermetically sealed. Wide range of applications includes fuel element temperature monitoring, high neutron flux alarm, low coolant flow and coolant temperature. Other interesting and important exhibits include a trip margin indicator, and a transistorized strip chart recorder for use with temperature and telemetering equipment.

Black Automatic Controls Ltd (921). A new range of diaphragm valves for high viscosity liquids will be shown.

British Electrical Development Association, The (301) have a small scale working automatic production plant as their exhibit.

British Federal Welder & Machine Co Ltd (216) will show details of a completely automatic conveyorized hopper-fed projection welding line. Requisite component is fed on a conveyor belt through a series of machines supplying all stations for a predetermined time cycle.

British Physical Laboratories (311). A new 10 c/s-100 kc/s valve voltmeter will be shown.

British Tabulating Machine Co Ltd (411) will give a display on production planning by electronic computer.

S. G. Brown Ltd (416) will display miniature fractional h.p. motors and a high speed recording camera.

British Thomson-Houston Co Ltd (508). Exhibits include a general purpose induction heater with a continuous output rating of 25 kW and a peak intermittent rating (50 pct duty cycle) of 30 kW.

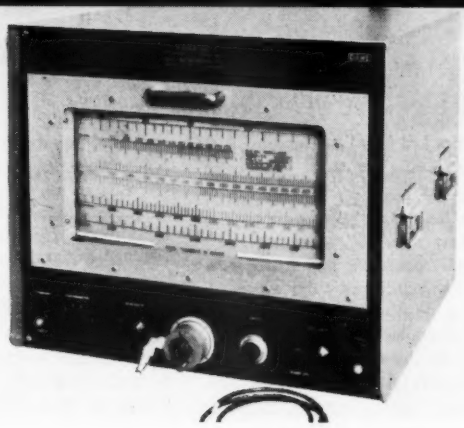
Burndept Ltd (421). A scintillation counter is used in the sensing head of a new thickness gauge. Output from the ratemeter circuit is fed into a backed off valve voltmeter so that f.s.d. of meter can correspond to very small changes in count rate. Also on view will be a portable battery-operated fast neutron monitor designed in conjunction with AERE, employing a proton recoil proportional counter as the neutron chamber, and a welder working on an unusually high frequency using pre-heating of the electrodes.

Cambridge Instrument Co Ltd (601). New measurement instruments shown will include one for continuously recording and analyzing dissolved oxygen down to minute concentrations (gas-phase transfer type); uses a novel electrochemical method of detection and has been designed to meet requirements of modern high pressure and high temperature steam systems now employed in nuclear and other types of power station. Features highly stable zero, few glass components and a means of detecting and assessing size of errors due to leaks in the equipment itself.

Crompton Parkinson Ltd (309). The central feature of this stand will be the new 240 degree 11 in. scale portable instruments, including ammeters, wattmeters and speed indicators.

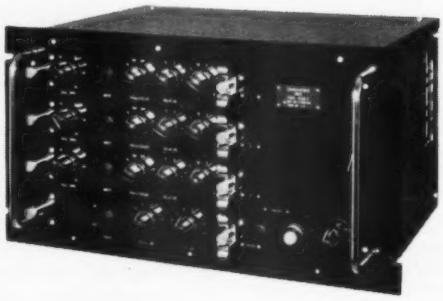
Crosby Valve & Engineering Co Ltd (606). Transparent plastic bodies will illustrate path of flow through Mason Neilan percent piston control, small flow valves and a Crosby relief valve. Each valve can be remote manually controlled allowing flow at different openings to be observed,

AIRMEC — portable radiation monitor



DAWE—visigauge

DYNATRON—coincidence unit



DON'T MISS THESE

- **transistorized on-off controller** Bailey Meters
- **new thickness gauge** Burndept
- **new oxygen content analyser** Cambridge Instruments
- **new gamma backscatter gauge** Ekco Electronics
- **information presentation systems** Elliott Group
- **streamlined testing sieve shaker** Endecotts

and they discharge into a tank where the level is indicated and controlled by more Crosby instruments.

Dawe Instruments Ltd (419) will show a production model of their *1108 Visi gauge*. It measures thickness of material from one side by determining the fundamental natural frequency of vibration in the thickness direction and displays on a CRT giving comparison accuracy better than 0·1 pct. Can also be used to detect internal defects within materials.

J. Day & Co (Derby Works) Ltd (214). High spot of display will be new cable covering for use up to 1000°C.

Drayton Regulator & Instrument Co Ltd (296). *Hydroflex* metal bellows for temperature and pressure sensitive systems, vacuum gland seals, expansion joints, flexible couplings etc will be featured on this stand together with equipment using them for automatic control purposes, including boiler and process control devices, pneumatic instruments, pressure regulators, ventilation control units and shaft couplings as used in computers.

Dunford & Elliott (Sheffield) Ltd (919). *Lindar* automatic controls shown will include data system logging ambient temperature, number of visitors to stand etc, on an automatic typewriter, automatic weighing using digitizing attachment, and a digital voltmeter. A liquid dispensing system will be demonstrated delivering quantities of liquid pre-set on remote control. System can be set up from punched cards to print out details of deliveries on to a column printer.

Dynatron Radio Ltd (918). Among their range of nucleonic instruments will be a coincidence unit, available for first time commercially, containing a three-channel coincidence circuit which may be used in several different arrangements of coincidence and anti-coincidence. It will be demonstrated with a probe unit and a new scaling unit, using cobalt 60 as the radioactive source.

Ekco Electronics Ltd (505). Working displays of the latest developments in nucleonic gauge field will be exhibited—including a fully temperature-compensated measuring head for thin materials and a new gamma backscatter gauge employing transistors and printed circuit technique for measuring steel thickness where access is limited to one side only. Range of nucleonic measurement is extended to brass, steel or copper up to 0·4 in. thick by a new gauge employing a low-energy X-ray measuring head, and another new instrument employs an alpha source in conjunction with a scintillation counter and includes an automatic standardization system for correcting zero drift errors.

Elga Products Ltd (810) will exhibit a unit for mixed bed deionization, two or multi-column deionization or ion exchange chromatography. It includes samples of most ion exchange resins and will enable research workers to conduct pilot scale experiments in a scaled down plan prior to process use.

Elliott-Automation Group (403, 509, 408, 939). System illustrating various methods of presentation of process information from the simplest to the most complex will be shown on stand 403.

Equipment used will include instruments of Elliott Bros, Panellit Ltd, James Gordon & Co and Bristol's Instrument Co Ltd. Stand 509 will be mainly devoted to components and valves of Fisher Governor Co and James Gordon including a 4½ ton 15 in. pneumatically-operated flow-control valve by Fisher, and a variety of Gordon butterfly, sandwich and needle valves.

Display indicating equipment of Electroflo Meters Co Ltd and Sauter Controls Ltd will be on view at stand 408. Electroflo display emphasizes its work in fluid dynamics, automatic boiler control and remote control systems for public utilities. Sauter Control's display will include equipment for heating, ventilating and air-conditioning systems, including fully automatic installations.

On stand 939 Rotameter Manufacturing Co Ltd. Instruments for liquid flow measurements from 0·5 cc/min to several thousand gallons per hour, for gas flow measurements over a similarly wide range, and instruments for use with corrosive fluids.

EMI Electronics Ltd (506) will exhibit new stroboscopes and industrial television camera channels.

Endecotts (Filters) Ltd (704) will be displaying a new streamlined testing sieve shaker. Totally enclosed and fitted with anti-vibration mountings, the machine will demonstrate the rapid analysis of particles on transparent rimmed test sieves—only setting and recording of result being needed.

English Electric Co Ltd (405). Reversing mill automatic programming equipment will be demonstrated by a model of a typical hot reversing mill together with the appropriate programming units, magnetic amplifiers, high frequency set and control gear. The mill and roller table speed, the screwdowns and the manipulators will be controlled. The English Electric Valve Co Ltd will show a working display using a specially developed direct viewing storage tube with variable persistance and brightness.

Ericsson Telephones Ltd (413) present a counting installation for nucleonic applications, consisting of a high speed scaling unit, e.h.t., amplifier-discriminator, logarithmic and linear ratemeters, and a timing unit. Also on view is scaling and timing unit. Three battery-operated portable radiation detectors will also be shown.

Ether Ltd (512). Temperature and process control equipment will be shown.

Evans Electroselenium Ltd (107). New absorptiometers and flame photometers on display.

Evershed & Vignoles Ltd (404) will exhibit new all-electronic process controller providing non-interacting control terms, a wide range of proportional, integral and derivative adjustments and facilities for inclusion of measuring and recording instruments. A demonstration of flow control particularly suitable for corrosive liquids will show this instrument operating from a magnetic flow meter and positioning a valve in a closed flow circuit.

Fielden Electronics Ltd (516) will exhibit two new industrial level controllers operating on the patented capacity method. Instruments incorporate printed circuits and front control knob enables set-point to be adjusted on site. Other features are triggered positive relay action and quick release chassis.

Fleming Radio (Developments) Ltd (700) will exhibit a miniature light-operated switch. It consists of a photo-conductive cell of the interleaved comb type connected via a two stage transistor d.c. amplifier to a relay.

Foster Instrument Co Ltd (519) will be showing their complete range of temperature measuring and controlling instruments including latest indicating and recording controllers of the electronic potentiometric self-balancing pattern. Introscopes on display will range from simple outfit for radial inspection of $\frac{1}{8}$ in. dia holes to a limited depth up to jointed introscopes with considerable operative lengths. Interchangeable viewing heads give different angles of view.

Foxboro-Yoxall Ltd (305) gives first view of new direct mounted liquid level transmitter, operating on the force balance principle. It measures liquid level in open or closed vessels and transmits an output air signal direct to standard 3-15 psi receiver/recorders and controllers; sensing diaphragm capsule is flange mounted direct to the side of the tank.

DON'T MISS THESE

- **new industrial level controllers**
  Fielden Electronics
- **miniature light-operated switch**
  Fleming Radio
- **new tank contents instruments**
  KDG Instruments
- **packaged transistor oscillators**
  GEC
- **continuous gas concentration recorder**
  Infra Red Developments
- **new plastic scintillators**
  Nash & Thompson

The General Electric Co Ltd (410) will be showing a wide range of valves, among them microwave, hydrogen thyratron, xenon rectifier, and geiger tubes, semi-conductor devices will comprise germanium and silicon diodes and transistors. Other exhibits include 'packaged' transistor oscillators and process heating equipment is represented by an 18 kW high-frequency induction heater and a 4 kVA electronically-controlled spot welder.

Glass Developments Ltd (422). The laboratory fractioning column should be seen.

Hanovia Lamps (215) will be showing range of ultra-violet and infra-red equipment, including electronic instruments involving use of a u.v. source.

Hendrey Relays Ltd (929). A new 20 amp 440 V a.c. 4 pole changeover contactor of very small size is the starpiece of this stand.

Honeywell-Brown Ltd (407) will display complete control systems. One for furnace temperature control will show programme controllers operating in tandem with new indicating millivoltmeter controllers providing high limit protection: control of flow, liquid level and pressure in a fractionating column employs differential converter transmitters including new one with range adjustable between 0–5 in. and 0–25 in. w.g.

Hunt & Mitton Ltd (712) will be showing a range of process control valves up to 14 in. bore. Usual characteristic is linear obtained by the use of a V-ported valve block. Valves suitable for working pressures up to 6000 psi, operated by air diaphragm tops, for control of presses and other hydraulic machinery in conjunction with time cycle controllers will be on view.

Alfred Imhof Ltd (911) in addition to wide range of cases, racks, consoles and accessories will show a forced ventilation rack fitted with an exceptionally powerful fan and semi-sealed doors useful where high degree of cooling is required. Also shown will be the 'Imlock' do-it-yourself system of construction useful for prototype work.

Infra-Red Development Co Ltd (717) will display an instrument for continuously recording concentration of a particular gas or vapour in a gaseous mixture by measuring its 'optical' absorption in the infra-red spectrum. Mixture is drawn through an isolated tube exposed to infra-red radiation and detector uses pure sample of gas to be measured so that device has complete resolving power. Measurement can be made at pressures other than atmospheric and provision is made for alarm switches to operate if concentration exceeds pre-determined limit.

Isotope Developments Ltd (706). Highlight is the inexpensive *gamma switch*, consisting of a halogen-quenched geiger-müller tube and a relay built on to a printed circuit chassis. Its many applications include control of high and low level of material in a hopper, or density or flow failure detection in pipes without the necessity for holes or inside electrical or mechanical connexions.

KDG Instruments Ltd (201) expands its range of tank contents indicators, controllers and recorders to the production of both mechanical and continuous reading pneumatic types and will also show an entire electrical system for the indication of tank contents generally.

Kelvin and Hughes (Industrial) Ltd (607) show new multi-channel dynamic strain recording equipment.

George Kent Ltd (402). A working model of flow-ratio control will be demonstrated, using water-flow lines, by means of two *Commander* models, a pneumatic flow recorder-transmitter and a flow recorder-controller. Also on view will be *Mark 2A Multelec* recorder, previously reserved for the atomic energy industry but now on general release for temperature and millivoltage applications and the new *Dall* orifice.

Langley London Ltd (900). Electrical insulation materials will be shown on this stand.

Laurence, Scott & Electromotors Ltd (102). Exhibits of standard products will include a wide range of magslips, synchros and servo-motors, together with

tachogenerators having particularly low output ripple content and high output voltage per unit of speed.

Lintronic Ltd (625) present a hot film anemometer for measuring and recording mean and turbulent velocity components of gas or water. Has been used in the study of complex flow characteristics of coolants—CO_2 and heavy water over a variety of surfaces. The sensing element is a small glass rod with the wedge end coated with platinum film which is heated to a predetermined temperature: when gas or water flows over it film is cooled but electronic feedback systems keeps temperature constant, increase in heating current giving measure of the flow velocity.

Magnetic Devices Ltd (313). Among the exhibits shown will be a new sub-miniature double pole changeover relay which is hermetically sealed in a can similar to the type used to enclose miniature crystals. Other new relays on show will include double pole and four pole miniature hermetically sealed types, multicontact Post Office type relays and a 30 amp single pole contactor.

Marconi Instruments Ltd (405) will show transportable equipment designed for panoramic radiography of circumferential welds or of objects placed in a circle. It comprises an h.t. generator/tube unit and a control unit. In addition to a 360 degree beam, normal cone beam techniques can be employed and several types of insert are available.

Measurement Ltd (809). A large panel illustrating equipment for dispensing preset quantities of liquids will be displayed. It is actuated by a rotary piston type of meter and preset quantity is selected by push button, rotary switch or punch card reader unit.

Metropolitan-Vickers Electrical Co Ltd (401) will exhibit a tape reader designed for rolling-mill screwdown programming, an analogue computer, a *Magistor* static switching control system and a 4-channel timer; also on view—a high-speed data transmission system, a flameproof *Magistor* photoelectric relay unit and a vapour phase chromatograph for the analysis of gases and volatile liquids.

Morgan Crucible Co Ltd (414). Display will include resistors, bearings and pump seals.

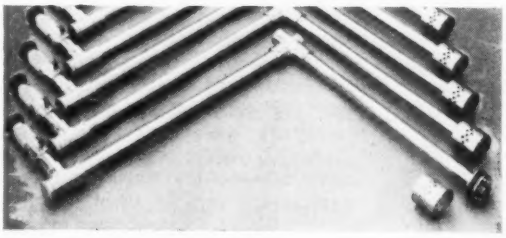
Muirhead & Co Ltd (600) will demonstrate their transfer function analyser. Intended for measuring the transfer function of servo systems and electrical networks, the equipment comprises a low frequency decade oscillator, a phasemeter and a tuneable filter. Open-loop and closed-loop measurements will be made on a model servo system.

Mullard Ltd (501) will present nuclear magnetic resonance equipment intended primarily for high resolution proton spectrography, but easily adaptable to other nuclei. The method employed has potential uses in process control operations as well as chemical research. Important features are a very uniform magnetic field and high stability. Also on view will be new equipment for detecting contamination incorporating six units: two each for detection of alpha and beta-gamma radiation on hands and one each for alpha and beta-gamma radiation on clothing. The equipment can operate on all stations simultaneously to enable large numbers of people to be checked quickly.

Nalder Bros & Thompson Ltd (609) will show new electrostatic voltmeters for use up to 10 kV.

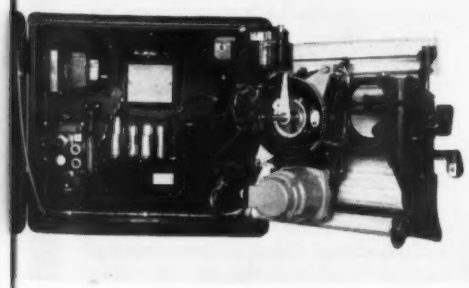
Nash & Thompson Ltd (304) will show additions to range of plastic scintillators. New material used—a combination of B.B.O. and p-terphenyl phosphors—forms a most efficient plastic scintillator; has a pulse height of 50 pct of that of an anthracene crystal of same weight and decay time is order of 2–3 $\times$ 10^{-9} sec. Other products are canned and tested sodium iodide crystals and liquid organic scintillators. Metallurgical instruments include a new coating thickness meter.

C. A. Norgren Ltd (708). Automatic drain air purifiers will be shown, further improved by use of new draining mechanism. These filters, which drain whether or not compressed air is flowing can now



FOSTER INSTRUMENTS—introscopes

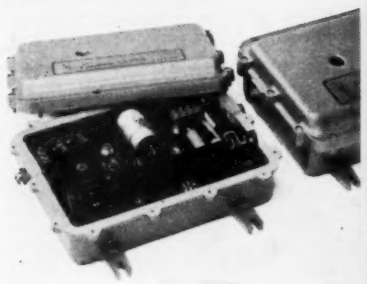
EVERSHED & VIGNOLES—mk IV process controller



GEORGE KENT—mk 2A Multelec recorder

ERICSSON—geological survey meter

INFRA-RED DEVELOPMENTS — gamma switch



be used over a range of 5 to 250 psi up to 200°F.

Philips Electrical Ltd (409) will give first view of a new series of nuclear research equipment including pre-amplifier, linear amplifier, electronic timer, single channel analyser, h.t. power unit and 5 kV supply. Other newcomers are a strain gauge for the measurement of deformation in concrete, a transistorized pocket radiation meter and two pocket dosemeters. There will be a display of equipment including isotope containers and remote handling tongs, lead lined doors etc. and exhibited for first time will be a reactor control panel of a type now in production for the Netherlands atomic authorities.

Plessey Development Co Ltd (930). This stand will be divided into four main groups: cold moulded insulators for arcing zones, high temperature use etc by Rosite Ltd: synchros and servo components by Ketay Ltd including a new 400 cycle prevision integrating tachometer specially designed for speed control: electrical connectors by Modern Acoustics Ltd and seamless, flexible metallic hose by Power Auxiliaries Ltd for conveyance of liquids or gases at high pressure.

Plessey International Ltd (908). Nucleonic equipment will include 4 lb battery-operated radioactivity survey meters covering the range 0–500 r/h. Other items are memory cores and matrices for storage devices in computer circuitry, a transistorized electronic control with tape reader, and hydraulic pumps and electrical actuators for control systems.

R. B. Pullin & Co Ltd (312) will be showing the new Pullin-Kearfott synchros and servomotor and a series of permanent magnet high efficiency d.c. motors.

W. G. Pye & Co Ltd (503) will show new gas liquid chromatography equipment designed for short column work and using only 5-15 pct proportion of liquid phase. Atomics Division exhibit a mock hot cell using two new master slave manipulators, and closed circuit TV from industrial TV division in conjunction with an absorptiometer by Unicam Instruments Ltd, who exhibit also a new flame spectrophotometer. Viewing window for the hot cell is by courtesy of Mendip Chemicals Ltd. Among instruments on this stand will be amplifiers and vibrators by W. Bryan Savage Ltd and a 4 π proportional counter by Labgear Ltd. This is a prototype instrument designed for the measurement in methane of low energy beta and alpha particle emissions. Labgear exhibit also an industrial scintillation counter now in production.

Quickfit & Quartz Ltd (804). Interchangeable laboratory glassware forms this firm's display.

Racal Engineering Ltd (106) will show universal counter/timers capable of counting to one million events per second with a display of plug-in units for those wishing to construct their own equipment. A new print-out system capable of printing 60 cpm will be displayed for first time.

Rank-Cintel Ltd (314) will show a fully transistorized portable unit for measuring time in the range 1 microsec to 1 sec in steps of 1 microsec. Also on view—a universal counter/timer for measuring time per unit event from 3 microsec or events per unit time in range 30 c/s to 1 Mc/s, and a closed circuit television system for flame viewing.

W. H. Sanders (Electronics) Ltd (515) will exhibit a range of encapsulated transductors consisting of five frame sizes giving outputs from 0·045 to 11·5 W d.c. for 50 c/s supply frequency and 1·1 to 145 W d.c. with 400 c/s, using the auto self-excited connexion. The high grade nickel iron laminations are inserted and sealed after the windings have been encapsulated in an epoxy resin, thus avoiding damage to the strain-sensitive core material.

Sangamo Weston Ltd (914) will exhibit latest developments in single phase and polyphase watthour meters.

Semiconductors Ltd (618). First view of new factory's range of transistors. Surface barrier group includes examples for RF and video amplifiers and switching circuits—cut-off 30-90 Mc/s. Also shown will be high gain micro-alloy transistors working up to 40 Mc/s, micro-alloy diffused transistors up to 500 Mc/s for oscillators or 200 Mc/s for amplifiers, high speed switching circuits with rise and fall times of a few millimicrosecs and RF and video silicon alloy and germanium power transistors.

Servomex Controls Ltd (916). On view will be units for construction of d.c. servo systems including a servo amplifier giving full range of field control on standard split field motors requiring 80 mA for full torque and a 'constant current' armature supply.

Short Brothers & Harland Ltd (612) will give first show of a new miniature analogue computer. It is a d.c. amplifier unit capable of solving second order differential equations; a full size computer can be gradually assembled as need arises by adding other computing equipment or linking to further d.c. amplifier units.

Sierex Ltd (710) will present a new method of obtaining a high fidelity direct graphical record. A jet of ink is directed on the paper and direction of stream influenced by a galvanometer system; can follow up to 1 kc/s.

Simmonds Aerocessories Ltd (902). An extensive range of fluid handling instruments, including flowmeters, liquid level controllers, gauges and valves, will form the exhibit at this Company's stand.

Solartron Electronic Group Ltd (502) will show a gyro response test console to measure the transfer function and damping characteristics of rate gyros. It discriminates in favour of the fundamental frequency to give accurate readings irrespective of harmonics and unmasked by irrelevant oscillations. Also on view—an oscilloscope with more than 2 pct accuracy, to be used as a measuring instrument as well as display unit, and a cybernetic training machine for Hollerith operators.

Southern Instruments Ltd (808). Industrial division presents its electronic gauge for semi or fully automatic indication and control of dimension tolerances—reads total deflexion of ±0·005 in. with accuracy extending down to 0·00001 in. Cable carries signal from robust gauge head to indicating unit and tolerance limits can be indicated by coloured light signals. Relay outputs are available for automatic sorting or machine control.

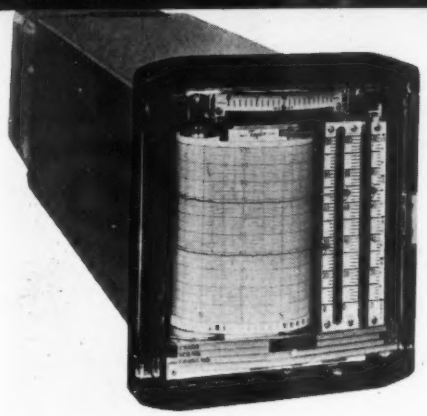
Computer division will give working demonstrations of the cathode ray Polarograph, and systems for speedy analysis and reduction of analogue trace records to digital form including a new multichannel system.

Sperry Gyroscope Co Ltd (303). A control rod fine position indicator for use in nuclear reactors will be on view. This is servo driven and presents information on the general position of the control rod and its absolute position within 0·1 mm together with direction and speed of movement.

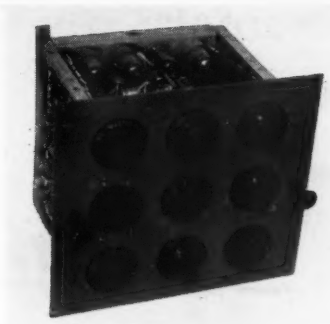
Sunvic Controls Ltd (511). New multiplying relay will be demonstrated. It multiplies, divides, squares and extracts square roots of analogue signals in the 3-15 psi range. Other features are first view of latest data logging equipment and a working graphic panel incorporating miniature recorders and recording/control stations, plug-in controllers, liquid level controller, pressure regulators, pneumatic timer and potentiometric recorders.

DON'T MISS THESE

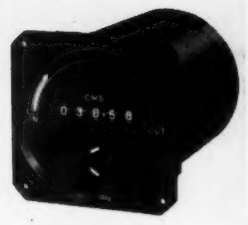
- **nuclear research equipment**
  Philips Electrical
- **4 lb radioactivity survey meters**
  Plessey
- **universal counter/timer**
  Rank-Cintel
- **new range of transistors**
  Semiconductors
- **high accuracy oscilloscope**
  Solartron
- **new portable flaw detector**
  Ultrasonoscope



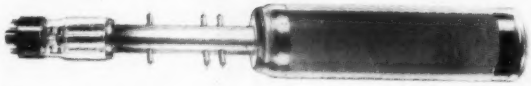
TAYLOR CONTROLS—new transcope recorder



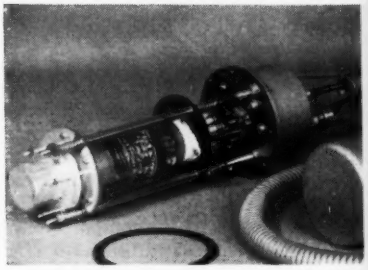
SHORT BROS—time delay unit for computer



SPERRY GYROSCOPES—control rod position indicator



20th CENTURY ELECTRONICS—travelling wave c.r.t.



LABGEAR — industrial scintillation counter

Taylor Controls Ltd (602) will be showing new miniature Transcope recorder—panel cut out 6 × 6 in.—which receives three recorded or indicated variables, using *Servomatic Power Pens* ' 150 times more powerful than the conventional type ' on a 4 in. 30-day chart.

Technical Ceramics Ltd (949). Transducer sub-assemblies suitable for flaw detection will be exhibited.

Telegraphic Construction and Maintenance Co Ltd (942) will exhibit a 77 pct nickel-iron magnetic alloy of high permeability.

Telephone Manufacturing Co Ltd (302) will demonstrate a new double change-over relay in an impulse corrector and re-shaping circuit.

20th Century Electronics Ltd (904) will present recently developed travelling wave c.r.t. Symmetrical deflexion of the electron beam on one axis is given by a pair of travelling wave deflecting systems of interesting design. The other deflecting plates are conventional

Ultrasonoscope Co (London) Ltd (422). A console model flaw detector allowing control and variation of a greater range of variables than in the standard portable apparatus will be exhibited. Features include rectified or unrectified signal display and multi-channel band width selector. Also on view is an improved portable flaw detector with new quick recovery amplifier design increasing near surface flaw resolution.

Venner Electronics Ltd (953) will demonstrate a frequency meter employing 110 transistors.

W. Watson & Sons Ltd (503) will show new industrial stereoscopic microscope.

ALSO SHOWING

ADS Relays Ltd, 936; Aircraft-Marine Products (Great Britain) Ltd, 938; Airflow Developments, 927; Air Trainers Link Ltd, 933; Aldis Brothers Ltd, 312; Alexander Controls Ltd, 917; All-Power Transformers Ltd, 934; Amplivox Ltd, 937; Analytical Measurements Ltd, 205; Anglo-Netherland Technical Exchange Ltd, 721; C. Baker of Holborn Ltd, 518; Baldwin Instrument Co Ltd, 202; R. & J. Beck Ltd, 300; Belling & Lee Ltd, 941; Bellingham & Stanley Ltd, 614; J. B. Blakeborough & Sons Ltd, 417; British Electric Resistance Co Ltd, 943; British Ermeto Corporation Ltd, 219; British Power Transformer Co Ltd, 943; British Rototherm Co Ltd, 932; Camlab (Glass) Ltd, 701; Cass & Phillip Ltd, 203; Chance-Pilkington Optical Works, 611; Coley Thermometers Ltd, 200; Colvern Ltd, 928; Combustion Instruments, 315; Cooke, Troughton & Simms Ltd, 517; Cossor Instruments Ltd, 907; Counting Instruments Ltd, 909; Stanley Cox Ltd, 312; J. F. Crosfield Ltd, 925; Croydon Precision Instrument Co, 924; Dargue Bros Ltd, 944; Donvin Instruments Ltd, 312; Ega Electric Ltd, 713; Electrical Remote Control Co Ltd, 723; Electrolytic Engineering Ltd, 948; Electro Methods Ltd, 512; Electronic Components, 728; Electronic Instruments Ltd, 931; H. J. Elliott Ltd, 702; EMO Instrumentation Ltd, 218; Everett, Edgcumbe & Co Ltd, 516A; Fairey Aviation Co Ltd, 105; Faraday Electronic Instruments Ltd, 503; Firth Cleveland Instruments Ltd, 902; Fischer & Porter Ltd, 207; Flatters & Garnett Ltd, 617; Formica Ltd, 300; General Radiological Ltd, 715; Gloster Aircraft Co Ltd, 621; Goodmans Industries Ltd, 220; Hall Harding Ltd, 604; Hallan, Sleigh & Cheston Ltd, 946; Hatfield Instruments Ltd, 709; Headland Engineering Developments Ltd, 725; Hilger & Watts Ltd, 306; T. & W. Ide Ltd, 800; Industrial Pyrometer Co Ltd, 945; Integra-Leeds & Northrup Ltd, 307; James A. Jobling & Co Ltd, 217; Kerry's (Ultrasonics) Ltd, 425; Laboratory Equipment (London) Ltd, 520; Lawes Rabjohns Ltd, 940; Livingston Laboratories Ltd, 412; Lodge Plugs Ltd, 720; Magnetic & Electrical Alloys Ltd, 942; E. N. Mason & Sons Ltd, 504; Measuring Instruments (Pullin) Ltd, 312; Microcell Electronics, 514; Microwave Instruments Ltd, 948; Mine Safety Appliances Co Ltd, 920; Minerva Detector Co Ltd, 901; Ministry of Supply, 903; MSS Recording Co Ltd, 952; Nagard Ltd, 213; Negretti & Zambra Ltd, 507; New Electronic Products Ltd, 619; Newmarket Transistors Co Ltd, 503; New Western (Engineering) Ltd, 100; Nottingham Thermometer Co Ltd, 945; NSF Ltd, 802; Optical Works Ltd, 615; W. Ottway & Co Ltd, 616; Ozalid Co Ltd, 510; Painton & Co Ltd, 209; Pan Ocean Ltd, 716; K. S. Paul Ltd, 624; Payne & Griffiths Ltd, 805; Bruce Peebles & Co Ltd, 923; Power Controls Ltd, 313; Precision Tool & Instrument Co Ltd, 722; Quickdraw Co Ltd, 110; Radiovisor Parent Ltd, 806; Research Utilities Ltd, 703; Recorder Charts Ltd, 103; Reilly Engineering Ltd, 905; F. C. Robinson & Partners Ltd, 211; Samson Controls (London) Ltd, 935; D. Shackman & Sons, 204; Shaw Moisture Meters, 915; Siemens Edison Swan Ltd, 308; Smiths Industrial Instruments Ltd, 109; Society of Instrument Technology Ltd, 101; South London Electrical Equipment Co Ltd, 212; W. F. Stanley & Co Ltd, 418; Stanton Instruments Ltd. 803; Technical Sales, 627; Technograph Electronic Products Ltd, 912; Teledictor Ltd, 724; Thermal Syndicate Ltd, 603; Tintometer Ltd, 947; Ronald Trist & Co Ltd, 605; Ernest Turner Electrical Instruments Ltd, 910; Vactric (Control Equipment) Ltd, 906; Victoria Instruments Ltd, 312; Wade Couplings Ltd, 719; Wayne Kerr Laboratories Ltd, 104; A. West & Partners Ltd, 108; West Instrument Ltd, 707; Western Manufacturing (Reading) Ltd, 423; Williams & James (Engineers) Ltd, 807; Worcester Royal Porcelain Co Ltd, 705; W. S. Electronics (Production) Ltd, 206; G. H. Zeal Ltd, 801.

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Switzerland Metrohm, 628.

Sweden Sivers Lab, 628.

Austria Dipl. Ing. Janovsky & Popp., O. H. G., 521.

Germany Allgemeine Elektrizitäts Gesellschaft, 521; Bodenseewerk Perkin-Elmer & Co, 523; Firma Degussa, 420; Gesellschaft für Elektrische Zugbeleuchtung MBH, 521; Heinz-Gunther Neuwirth, 415; Klemt Elektronische Messgeräte, 415; Max Funke, K. G., 415; Rohde & Schwarz, 522; Siemens & Halske A/G, 620; Wissenschaftlich Technische Werkstatten, 628.

France 950 & 951; Chauvin-Arnoux et Cie, COMEF, Constructions Electriques, R. S., Ferisol, Intertechnique, Albert Le Boeuf et Fils, Legpa, L. Leiubray, Lemouzy, Nardeux, Photo Stress France, La Physiotechnie, SAMA, SEFRAM, SNRS France Automation, La Technique Electronique ' Telec '.

Magnetic memory scaling system

indicates pulses received

E. FRANKLIN, PhD. AMIEE
AERE, Harwell

J. B. JAMES
British Tabulating Machine Co Ltd

MAGNETIC CORES employing material with rectangular hysteresis loops are essentially two-state devices, the states of magnetic remanence existing after saturation in either of two opposite directions being well defined. Many such cores are now employed in place of other two-state devices, such as valve flip-flops, in electronic computers, data-handling equipment etc. The energy required to change the stored information is small, and none is consumed in retaining it, since it is stored in the form of remanent magnetic flux. This results in great power economy and cool running, and also gives the useful feature that the information can be retained, even when the equipment is switched off. Further advantages are small size, high reliability and extreme ruggedness.

A scale-of-ten may consist of a ring of ten magnetic cores in which the polarities of the remanent flux of nine are all the same, while that of a tenth is reversed. The coupling circuits between the cores are such that, on the application of a driving pulse (a pulse to be counted), the pattern of polarities moves round the ring by one core position. A pulse can be passed to the next scale-of-ten on each passage of the pattern through one particular position. A number of circuits capable of bringing about this progression of a pattern of polarities have been described in connexion with shifting registers and switching circuits for electronic computers, etc (*1, 2, 3, 4*). The drive pulses can conveniently be obtained from transistors.

As a result of the non-power consuming nature of the information storage, it is difficult to obtain an indication of the state of the cores, and therefore of the number of pulses received, by the usual arrangement of indicator lamps, etc, without considerable complication of the electronic circuits. However, an indicator has been developed in which the currents flowing in the scaling circuit magnetize thin strip cores of nickel-iron mounted around an astatic pair of compass needles, the needles being attracted by the one strip magnetized one way and repelled by the other nine magnetized oppositely.

There are two main types of magnetic shift register suitable as a basis for a scaling system. In the first, the cores are arranged in cascade and are driven from one current pulse source. The stored information is transferred from the cores to an equal number of capacitors during the drive pulse, and fed back to the cores one step forward at the end of the drive pulse. In the second type of circuit, the cores are connected in two lines (rings in a scaling circuit) and the stored information is moved alternately from one set of cores to the other, always in a diagonally forward direction, by applying the drive pulses alternately to each line of cores.

The first or 'single-phase' type has the advantage of simplicity, since the driving arrangements are more straightforward and the circuit can be arranged so that only one winding is needed on each magnetic core. However, it suffers from the disadvantage that the duration and amplitude of the drive pulses need to be maintained within inconveniently narrow limits. In the 'two-phase' type, the duration of the drive pulses only has to exceed a minimum value, there being no upper limit; the tolerance on amplitude is much greater and the power efficiency is higher. An even better basis for a scaling system is a circuit which was originally developed to perform the function of a uniselector. This circuit, which also is a two-phase one, allows very wide ranges of variation of pulse duration and amplitude and has a still greater power efficiency.

The two-phase drive circuit consists merely of two additional magnetic cores and two transistors, both of which are non-conducting in the periods between pulses. The memory as to which phase shall be driven on each pulse is retained by the two magnetic cores.

The only standing current taken is that due to the collector current of the drive circuit transistors, which can normally be neglected. The power required is therefore proportional to the count rate and that required for a complete scaling equipment is little more than is required for the first scale-of-ten. In a typical circuit using ferrite cores of 2 mm outside dia this was about 3 mW per 1000 cps. The resolving time was 3 microsec, being limited by the transistors used.

The mechanical arrangement of the indicator is shown in fig 1. The compass needles are magnetically balanced

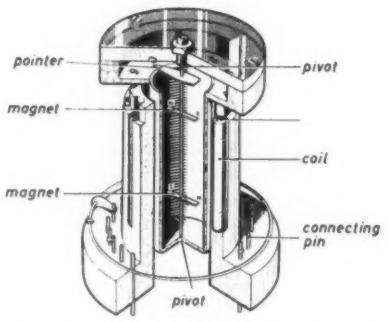

Fig 1 Cores magnetized by scaling circuit currents control compass movement

to nullify the effect of the earth's magnetic field and other stray fields, and mechanically balanced to make it possible to operate the indicator without error in any position. It must be designed to make the most of the small available energy, and this demands a high remanence in the nickel-iron magnetic cores. These are therefore made long (about 1 in.) and of small cross-sectional area, using an alloy with a rectangular hysteresis loop and a high coercive force (1·5 oersted) obtained by special heat treatment. The moving system will not, of course, follow a high count rate, but will take up the correct position on the cessation of a count.

It now appears quite feasible to design the indicator cores so that they can perform the function of the memory cores in the counting circuit itself, thus eliminating the need for separate ferrite cores. In addition to the economy in cores, this would result in a reduction in the resolution time of the circuit.

References

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3. Loev, D., Miehle, W., Paivinen, J. and Wylen, J., *Proc IRE* 1956, *44* (2) pp 154-162
4. Karnaugh, M., *Proc IRE* 1955, *43* (5) pp 570-584

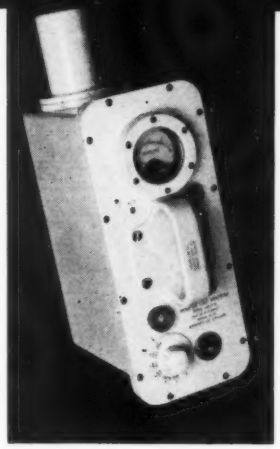

Fig 1 Small and compact, the instrument weighs 17½ lb. Visual and aural indication are provided

Based on a Harwell design, this new instrument by Burndept will simplify dosimetry measurements

A portable fast neutron monitor

W. G. SPARKE
Harwell

P. K. TOMKINS
Burndept Ltd

IN SEVERAL TYPES of instrument designed to measure the intensity of a fast neutron flux for dosimetry a knowledge of the mean neutron energy is required before the biological dose can be determined. The instrument described here provides a meter indication which is proportional to the biological dose over a wide range of fast neutron energies, and thus can simplify the task of the health physicist.

Values for the maximum permissible level (mpl) of neutron flux intensity as a function of neutron energy have been recommended by the International Commission on Radiological Protection (*1*) and are shown in table I.

TABLE I

Maximum permissible levels of neutron flux recommended by the ICRP

neutron energy		neutron flux, n/cm²/sec
0·025	eV	2000
10	eV	2000
10	keV	1000
0·1	MeV	200
0·5	MeV	80
1·0	MeV	60
2·0	MeV	40
3·0–10	MeV	30

A counter based on these recommendations has been described by Dennis and Loosemore (*2*) and forms the basis of the present instrument. When it is correctly set up in its associated electronic circuit, an indicated counting rate of 0·9 cps is produced by 1 mpl of fast neutrons of any energy in the range 0·1–15 MeV. Radiation monitoring instruments are often used in mixed radiation fields, and it is important that the detector be substantially insensitive to unwanted types of radiation. In this instrument a response equivalent to 1 mpl of fast neutrons is produced by not less than 200 mpl gamma radiation (1·5 r/h) and the same response is produced by 100 mpl thermal neutrons.

Polythene-lined counter

The counter consists of a 2 in. dia tube of stainless steel or copper, approximately 5½ in. long lined with polythene and divided into three cells by additional polythene disks, the cells having a common anode of 0·001 in. tungsten wire. The tube is filled to 17·3 cm Hg pressure of methane and 1·7 cm Hg of argon. The counter operates in the proportional region so that the ionization produced in the sensitive volume by protons in the hydrogenous wall and gas, which recoil following collision with neutrons, is collected at the anode with a multiplication factor of about 10^3. By the correct choice of gas pressure, cell dimensions and operating discriminator bias the response of the gas and the radiator slabs can be made to match within ±20 pct of the ICRP requirements.

The output pulse from the counter at the correct operating potential of 1400 V corresponds to the collection of $5{\cdot}5 \pm 2{\cdot}5 \times 10^6$ ion pairs, the uncertainty being due to small differences in the construction and gas filling of different counters. Dennis and Loosemore state that within the range 1300-1500 V the relation between mean pulse size S and applied voltage V is of the form

$$S = Ae^{0{\cdot}008V}$$

where A is a constant depending on the dimensions of S. This means that a change in applied voltage of 1 V produces a 1 pct change in the total charge collected.

E.h.t. for the counter is produced by a Cockcroft-Walton type multiplier stabilized within the limits 1350-1420 V by a corona stabilizer tube. The multiplier is fed from a conventional mechanical vibrator and step-up transformer and operates from 4 mercury cells; the vibrator circuit also produces a neon-stabilized, 60 volt positive supply for the amplifier and ratemeter. The tolerances in the corona stabilizer voltages, together with the uncertainties in the counter outputs noted above, result in a possible variation in the charge collected at the anode of $1{\cdot}5 \times 10^6$–10^7 ion pairs at the operating point, and the amplifier gain must be adequate to allow for this.

Anode current and gain stabilized

A simplified circuit of the amplifier and ratemeter is given in fig 2; details of the range changing and meter time constant circuits have been omitted for clarity. The anode potential of each amplifier valve V1 and V2 is a function of the ratio of two resistors and the voltage of the negative line, so that the anode current and hence the gain is stabilized. The gain control RV1 consists of a coarse step control and a fine control, and compensates for the variation in output of any combination of counter and corona stabilizer tube. The counting rate circuit comprises V3 and V4, and is triggered by feeding a negative pulse from the amplifier to the grid of V3 which is normally conducting. The circuit acts primarily as a pulse amplitude discriminator but also produces a change of current in V4 which is independent of the trigger pulse amplitude and lasts 1/10 of the mean spacing of the trigger pulses at full scale meter deflexion. The amplitude

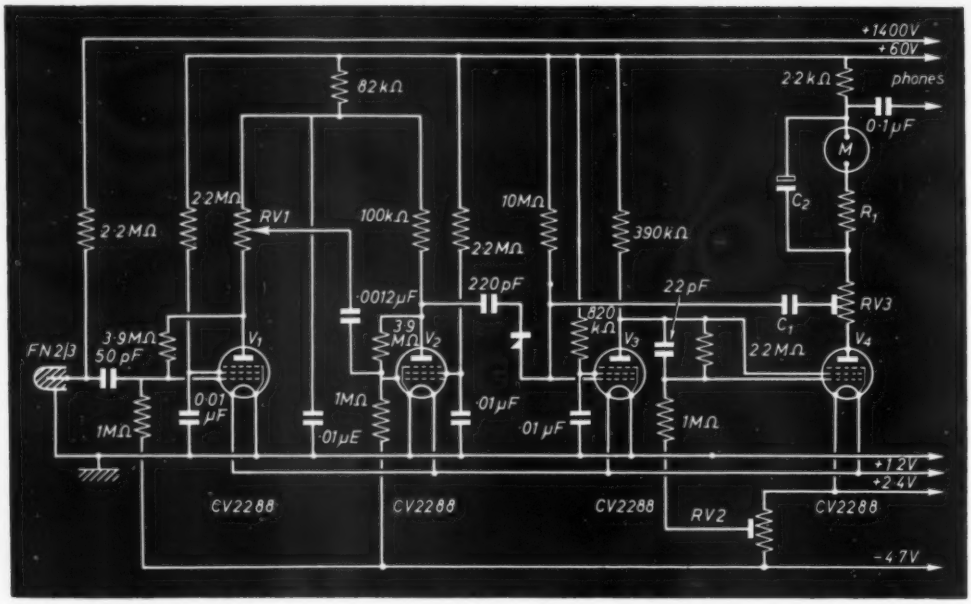

Fig 2 Simplified circuit diagram for the counter shows the counting rate circuit proper, V3 and V4, triggered by a negative pulse from the amplifier stage. V1 and V2

of the current change in V4 is 500 microamp, which for a mark-space ratio of 1:10 produces full scale deflexion on the 50 microamp meter.

The statistical loss for this mark-space ratio is 10 pct at f.s.d. and 1 pct at 1/10 f.s.d. on any range. The action of range-changing selects the appropriate value of the coupling condenser C1 and also of C2 and R1 which control the response time of the meter circuit (*3*). The ranges available are 0–4, 0–40 and 0–400 cps corresponding respectively to 5, 50 and 500 mpl of fast neutrons at f.s.d.

The discriminator sensitivity is set during manufacture by adjustment of RV2; V4 is then cut off in the absence of any counter output and hence the meter zero is not subject to drift. RV3 is used to set the scale calibration at f.s.d. on the middle range by injecting pulses into the amplifier input. The other ranges are calibrated by adjustment of a trimmer capacity on the appropriate value of C1.

The meter is also used to monitor the potentials of the battery pack, which has a life of about 50 hours for continuous operation. Both heater potentials for the valves are measured, batteries being replaced if the meter needle falls below a scale marking.

The −4·7 volt line is also measured and must be set up to the correct scale marking by the operator with the control provided. It is important that this potential be set to the correct value as it is the reference potential for current stabilization of the amplifier valves and triggering level of the discriminator. It is also the input voltage to the mechanical vibrator which generates the e.h.t. and h.t supplies.

A socket for earphones is provided on the front face. Fully sealed with 'O' rings and dessicated, the instrument is finished in cream Phenoglase and weighs 17½ lb.

Calibration jig

To set up the instrument to the correct operating point, the counter, which projects from one end of the case, is inserted into a special calibration jig (fig 3) containing a 5 mc radium-beryllium neutron source with a total neutron emission of 7×10^4 fast neutrons/sec. When unshielded the calibration source produces one mpl of gamma radiation at 1 yard and hence is surrounded by a spherical iron shield, giving a radiation level on the surface of the sphere of 100 mr/h. With the counter in position the indicated counting rate should be 2·4 cps.

When initially setting up a neutron counter this counting rate may be achieved by adjustment of the fine and coarse gain controls RV1, which are accessible through a small circular panel on the side of the instrument. Once the counter is set up these controls should not normally require adjustment.

It is common in instruments of this type having range changing facilities for the sensitivity to vary by about 10 pct from range to range. In the present instrument this will have the effect of increasing the gamma sensitivity slightly on the highest range (0–500 mpl) where this variation is of least importance.

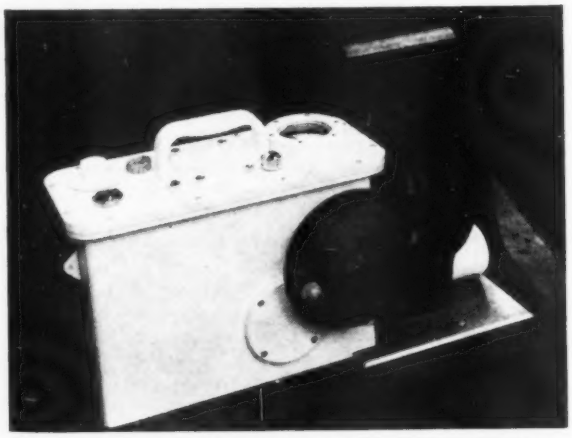

Fig 3 Calibration jig contains a neutron source and is surrounded by a spherical iron shield against gamma radiation. The counter tube can be seen projecting underneath the sphere

Acknowledgements

We acknowledge the help given by Messrs Dennis and Loosemore and their permission to use information from their paper in advance of publication elsewhere, and the directors of Burndept Ltd for their permission to publish.

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Cross Section by GRACCHUS

OFFICIAL assurances that the *Dreadnought* is to go ahead as a 'do-it-yourself' job seem to be getting a good deal weaker and it is now highly probable that the submarine will bear a strong family resemblance to the *Nautilus*—or rather the *Skate*, the productionized United States nuclear submarine. This is all to the good. If, as seems likely, the US Government has now been able to release to us all the information we need to build a submarine of the *Skate* type, it would seem to be the height of folly to persist with the home-made *Dreadnought*. After all, it took Rickover's team a good ten years to produce a practical nuclear-powered submarine and although we've been vaguely dabbling with them for years we have only fairly recently got seriously interested and it is unlikely that we've got very far. This is a totally different thing from power stations. Submarines are not for sale and there is no question of commercial competition with the United States over them. In fact we are allies and it would seem only sensible to pool resources. Possibly what will happen now is that the *Skate* reactor will be redesigned to British standards and specifications, but even this seems a waste. If in fact full American drawings have been made available, then we should go the whole hog even if it means making materials to US specifications. The great thing is to get the submarines quickly and at last this seems to have penetrated the Admiralty. The extraordinary cruise of the *Nautilus* under the polar ice, and now the *Skate*'s cruise across the Atlantic in eight days submerged all the way, have brought it home that this is the Navy of the future—if not of today.

THE APPROACH of the second Geneva conference must have been the cause of severely mixed feelings in the big power groups. For let us make no mistake, Geneva may be a big scientific conference, but it is also one of the greatest specialized publicity media ever devised and it is obviously desirable for the groups to get their name on as many papers as possible. The problem is how to do this without giving away any information of real value. So far there have been very few authoritative articles published on the new British power stations and these have invariably been skilfully written to avoid saying anything that could conceivably be of any value to a competitor. For Geneva, however, this will not do and the papers will simply not be acceptable unless they say something really worth saying. If the last conference is anything to go on, commercial security considerations should be at a discount and if Britain, nationally, is to put up a good show, NETAC—who are organizing the papers from British firms—must stand no nonsense.

All this is, of course, having its effect on the ordinary business of article writing and authors are reluctant to come up with anything as long as there's a chance of getting it accepted for Geneva, for a contribution there can practically create a reputation. Obviously articles are not going to dry up altogether but I don't think we can expect anything startlingly new or original until September. Just how ridiculous this is becoming is illustrated by a story I heard from the Editor the other day. An engineer who had had some part in designing it wrote an article for this magazine on a new experimental facility at an Atomic Energy Authority establishment. On submitting it for the customary clearance, however, it was banned—not on security grounds, but because someone in the establishment was writing a Geneva paper on the subject and didn't want himself scooped.

LIKE AVIATION and radio before it, atomic energy has frequently been blamed for various meteorological anomalies and I well remember a ghastly holiday in Brittany some years ago when conversations on the appalling weather invariably ended with a shrugged 'c'est la bombe atomique'. This question of whether atomic energy has affected climate has never, I think, been satisfactorily resolved but I have just been hearing a pretty powerful argument for the possibility that it might be affected in the future—although only in a minor way. For many years industrialized countries have been belching forth millions of tons of carbon dioxide as a product from the combustion of oil and coal. This gas absorbs strongly in the infrared and thus the atmosphere becomes heated from terrestial radiation. Apparently mean temperatures over inhabited areas of the world have increased by about 2 degrees over the last century and it is claimed that it is the carbon dioxide pollution that has done it. In the long run, as atomic energy takes over from coal and oil this source of carbon dioxide will disappear and the temperature will tend to return to its former value. This will however be an imperceptibly slow process and one in which we need take little subjective interest, I feel.

THE ORGANIZATION for European Economic Cooperation is really doing a very fine job in bringing the problems of nuclear energy before the European industrialists. They have just published the papers of their second *Information Conference on Nuclear Energy for Management* which was held last June in Amsterdam following the successful Paris conference earlier in the year. The proceedings are printed under the title *The Industrial Challenge of Nuclear Energy II* and they are obtainable from the Stationery Office. The papers are generally of a very high standard taken separately, but somehow the whole thing rather lacks cohesion and suffers from a certain amount of repetition. What, one feels, should be done now is for someone to take both the Paris and the Amsterdam papers together and make them into a comprehensive guide giving the industrialist everything he needs. The trouble about this however is that things move so fast that the book would almost inevitably be outdated before it was published, so perhaps it is best to get these out with as little delay as possible and let the reader get on with his own sorting out.

On Record

Just think of the money, materials and engineering talent that go into retooling for model changes to hasten last year's model on its journey to the junk pile. These over-powered cars are an idiotic waste. **Prof Harold C. Urey**

More has been spent on research into home perms than on investigating what goes on inside the head beneath the hair. **Rear-Admiral Hyman G. Rickover, USN.**

Ideas wanted for use of large quantities of graphite. **Advert in 'The Times'**

Nuclear power stations . . . are immensely heavy structures of concrete with the thirst of Odin, and may stand as Ancient Monuments long after they have ceased to be useful. **Mr J. R. James, Ministry of Housing and Local Government**

COMPANIES

SIMA follows up Canadian visit

The first team to follow up the visit of the Canadian Trade Mission to this country last December is now in Canada. The tour was arranged by the Scientific Instrument Manufacturers' Association and will include visits to the major industrial and scientific organizations in Toronto, Ottawa and Montreal. Aim is to extend the good will created during the Canadians' visit and increase trade in instruments between the UK and Canada. The team has the active support of the Dollar Exports Council and met its representatives on the eve of their departure to plan final arrangements for the tour.

Led by Laurie Woodhead of Cossor Instruments Ltd, the group is composed of senior executives of SIMA firms representing the fields of nucleonics, electronics, optics and laboratory equipment. Other members are D. A. Pitman, Electronic Instruments Ltd; P. E. Schilling, Stanton Instruments Ltd; Dr V. A. Sheridan, British Physical Laboratories; D. R. Stanley, Hilger & Watts Ltd; W. H. Storey, Unicam Instruments Ltd and J. R. Waite, L. Oertling Ltd.

Wider plate now

Aluminium plate for general engineering purposes can now be obtained in widths up to eleven feet for the first time in this country. It has been developed by Northern Aluminium Company Ltd by butt-welding two plates together to overcome limitations of rolling equipment that have in the past restricted plate to widths of 7 ft or less. Announcing this the company adds that it has strength and flatness such that for most purposes the presence of the weld need hardly be considered. The weld bead is ground flush so that the appearance is comparable with that of normal rolled material. The new plate will reduce the amount of welding that the user must do himself and ease the problems of designers hampered by the limitations of small plate sizes in arranging a structure.

Traces of grinding only remain to show weld in the 11 ft plate

The welding is carried out automatically in a special jig, and techniques have been developed for individual sizes and gauges of plate to prevent distortion. The strength of the weld, made in controlled conditions, is higher than can be ensured by welding during subsequent fabrication. Results of tests quoted include 0·1 pct proof stress of 8 ton/in.^{2} which is the same as the minimum demanded of unwelded material by BS 1476: NP5/6—the specification covering an alloy very frequently chosen for welded aluminium plate work. Other figures are a u.t.s of 16·3 ton/in.^{2} and an elongation of 11 pct (compared with 17 ton/in.^{2} and 12 pct specified).

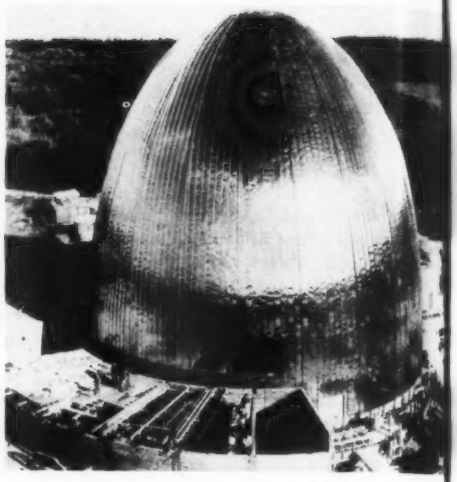
New Dounreay contract

Argon purifying plant is to be installed at Dounreay by British Oxygen Engineering Ltd. Announcing their contract from the AEA the company adds that its special plant will remove all traces of air from the gas and return it to its original state of high purity. Basically, the process is one of injecting hydrogen into the impure gas to act as a reducing agent by removing oxygen in the form of water, and of subsequent low temperature distillation for nitrogen removal.

Refrigeration for the process is provided by the use of liquid oxygen, and the contract awarded to British Oxygen Engineering includes the provision of two small liquid oxygen plants and a liquid oxygen storage vessel.

Atomic egg now open

Germany's first reactor—a 1 MW swimming pool type—officially opened recently near Munich, is the largest for research to be built in Europe under President Eisenhower's Atoms for Peace programme. It was designed and built by AMF Atomics and forms the main laboratory instrument of the University of Munich's new nuclear research centre. In addition to training students the centre will produce radioisotopes and conduct studies in chemical activation analysis in the effects of radiation upon materials. The 100 ft high aluminium sheathed dome, known as the 'atomic egg,' is surrounded by four supporting buildings which will serve as laboratories, heating and ventilation rooms and containment areas for the reactor's water shield when work within the pool requires the water to be temporarily drawn off.



AMF research reactor rises 100 ft from the flat farmlands around village of Garching, near Munich

A grant of $350,000 has been approved by the USAEC towards the cost of the nuclear research project in Greece, the 1 MW reactor for which is also being manufactured by AMF Atomics. It will use fuel elements fabricated by Babcock & Wilcox, US, and be housed in a building constructed by the Greek AEC, which will also build a hot laboratory for the project.

Zirconium or steel?

More than 60 representatives of US nuclear reactor designers and builders, electric power companies and the AEC, recently attended a symposium in New York on the economics of zirconium versus stainless steel as a cladding and structural material in power reactors. Sponsored by Columbia-National Corporation, the symposium presented the results of a detailed study made on five US reactors. Its purpose, according to general manager Gordon Kiddoo, is to assist industry in determining the specific applications where it is economically feasible to take advantage of the nuclear properties and corrosion resistance of zirconium.

The study—nearly a year in preparation—was made by Dr Manson Benedict, head of the nuclear engineering division of MIT. He was responsible for process design of the isotopes separation plant at Oak Ridge which produced the concentrated uranium for the first atomic weapons. Reactors studied were the natural uranium heavy water reactor of Atomic Energy of Canada Ltd, Atomics International's sodium-graphite reactor, the Westinghouse Yankee Atomic electric reactor, the merchant ship reactor by Babcock & Wilcox and General Electric's experimental boiling water reactor.

Columbia National's plant near Pensacola, Florida, for production of both commercial and reactor grade zirconium has just been completed.

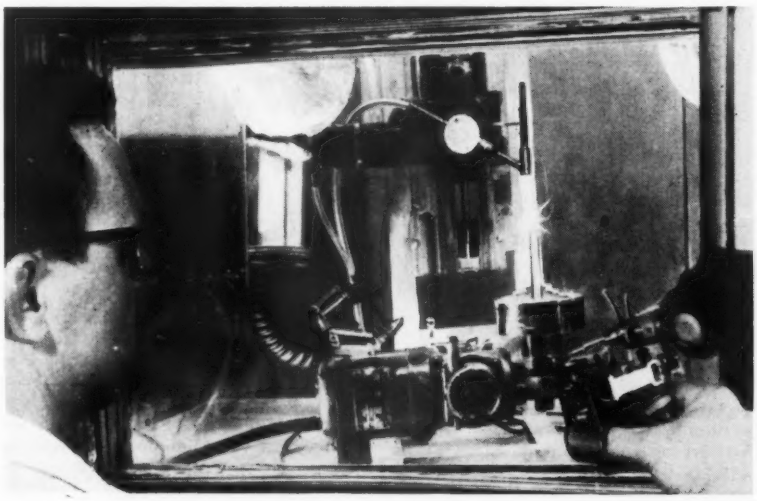
Biggest Polish order

Poland has placed a £M2½ contract with Metropolitan-Vickers Electrical Co Ltd for two 120 MW turboalternators. This is said to be the largest order placed with a UK firm by Poland since the war, and was secured in face of strong competition from German and Swiss firms. The two 3 cylinder turbines, the biggest ever ordered from this country for use in Europe, are directly coupled to hydrogen-cooled generators; they will be installed in a power station near Katowice in 1961.

Another recently announced overseas order for the company is a contract worth £M1½ for the construction of the Gach Saran Power System in Southern Iran. The scheme will comprise a 12 MW power station, transformers and transmission lines some 2500 ft above sea level, and will be commissioned in May 1960. Sub-contractors for the associated engineering are Richard Costain Ltd, and the transmission lines and cable work will be supplied by British Insulated Callenders Construction Ltd.

New isotope capsules

Radioactive materials in containers which can withstand high temperatures or corrosive solutions are now being produced for commercial use in the US by the Oak Ridge National Laboratory. Re-



Looking through several layers of special lead glass, a technician mechanically manipulates the Heliarc torch

motely controlled Heliarc welding is used to seal the materials, such as caesium-137, iridium-192 and cobalt-60, in stainless steel containers. These vary from 0·25 to 3 in. dia and may be used as single units or arranged in multiple units as an irradiation facility. In the initial production run at the laboratory radiocobalt with a total activity of 8000 curies was sealed in 34 capsules.

An inner cylinder holding the material is sealed by a plug which is Heliarc welded in place, and the outer stainless steel jacket closed by welding to the top a plug fitted with a handling post. 316 stainless steel was chosen because of its weldability and resistance to corrosion from chloride salts and the atmosphere.

The welding assembly—a two-piece stainless steel frame and motor driven positioner for both the torch and containers—is situated in a shielded cell equipped with mechanical manipulators, and controls for the motors are located outside near a viewing window.

The Laboratory hopes to use the same techniques in the future to seal large amounts of radioactive materials.

Handling Capenhurst data

The Capenhurst diffusion plant is to have the largest data handling system in Europe. Ordered by the AEA from Sunvic Controls Ltd, it will be delivered towards the end of the year, and will measure process gas, gland and motor bearing temperatures as well as motor currents and voltage and cooling water temperatures.

Each of the eight units will monitor signals from a group of four cells and be capable of scanning 260 points. In a central control room will be equipment for printing on demand a tabulated log showing the value at all measuring points on any of the 32 cells, together with cell identification and time of scanning. Any point exceeding pre-determined limits is shown in red, and an alarm printer fitted to each of the eight logger units records the time and value when any point goes off normal or returns to normal. Once again off normal values will be shown in red, and there will be a code to show whether a point is high, low or defective.

Additionally, two mobile print-out units will be supplied. These enable a complete log to be obtained at any time for any cell, without interrupting normal scanning of the other three cells in the group.

Furnace from Germany

A consumable electrode arc-melting furnace from Germany, reported to be the largest of its kind in Europe, will soon be delivered to William Jessop & Sons Ltd. It will form an addition to their existing vacuum-melting production plant and will treble production capacity for *Vacumelt* steels and *Hylite* titanium alloys, enabling them to produce ingots up to 24in. dia and 7000lb weight. The plant will incorporate full automatic control and safety equipment.

The company is the first in Europe to offer *Vacumelt* steels produced by this method on a commercial scale. They are said to have a very good standard of cleanness and low gas content, resulting in increased toughness and fatigue resistance. In the US production of steel by this method now accounts for 30,000 tons a year. Furnace manufacturer's UK agents are Fleischmann (London) Ltd.

In brief

Orders placed for **analogue computers** built by Short Brothers and Harland Ltd now total nearly fifty. Of these some twenty have been ordered during the past year, and forty are already in service in Britain and overseas. At Harwell recently, 150 engineers and physicists attended demonstrations at which the Short computer solved problems relating to the work of atomic reactors.

At the Wolverhampton factory of John Thompson Ltd, a *Unionmelt* Installation supplied by Quasi-Arc Ltd is now being used for the **welding** of cylindrical pressure vessels for atomic energy contracts. The welding head, mounted on a 17½ ft boom, can carry out external longitudinal and circumferential welding of vessels from 2½ to 18 ft dia or internal welding where the diameter exceeds 6½ ft. The roller bed can support, traverse, and rotate vessels of up to 18 ft dia, 30 ft in length and 48 ton weight.

Postgraduate students, attending the next one year nuclear engineering course of Queen Mary College, London, will experiment with AEI's MERLIN and a sub-critical reactor.

Early problems in AEA

Most manufacturers in this country regarded the Atomic Energy Organization in its early years as an upstart for which there was no long-term future, said Sir Christopher Hinton, CEGB chairman, in a paper to the Institute of Fuel last month. His Melchett lecture was largely an account of the problems faced by the production group pioneering atomic energy under his leadership. Now solutions have been found many of the difficulties have fallen into obscurity, and an impression remains of an unbroken flow of successes. 'I set out to humanize your view of the industry and show it has had problems and will go on having them,' he said.

When the production group was formed at the end of 1945 under Sir Christopher he had 'no staff, no office accommodation, and practically no information.' The remit was for a £M23 capital programme to build a single graphite-moderated water-cooled reactor for the production of plutonium with plant for the manufacture of the uranium fuel elements and other plant for the chemical extraction of the plutonium from them.

McMahon Act helped Shortly after the embryo staff had started work the Mc embryo staff had started work the Mcping all technological information from the US except in certain limited fields of research. 'It was the greatest blessing that could have befallen us,' said Sir Christopher. 'We would have been forced to follow America. As it was the Act withheld information on the design of their reactors and we had to think for ourselves: in doing this we were able to work our own approach and produce results which led to our present position of leadership.'

It was decided to build the uranium metal factory on the site of a disused poison gas factory at Springfields. The ICI had been doing research on the production of uranium metal but their starting point had been the highly purified Mallincrodt oxide. This had been imported from the US so now they had to evolve processes for extracting uranium from the ore and purifying it. There was obviously insufficient time for anything other than bench-scale work and a decision to use batch processes straight from the laboratory rather than continuous processes was almost inevitable. Sir Christopher recalled how the decision to order a bank of large Johnson filter presses was made on the basis of a sample of sludge in the bottom of a 4 oz bottle 'which was all the material we had on which to base a decision.' When the purified uranium had been obtained it had to be converted into uranium tetrafluoride and here the organization struck another snag. The wet process which the ICI had evolved required the use of very large quantities of platinum as a catalyst. Once again a calculated risk was taken. In spite of the fact that only bench-scale laboratory work was available to support it, an alternative dry way process using anhydrous hydrofluoric acid and working at 600°C was adopted. It was cheaper and avoided the problem of platinum supply though factories had to be constructed to produce the acid.

Uranium too brittle The next step was reduction of the uranium tetrafluoride to metallic form. Here the ICI had done extensive work and good information was available. 'Indeed their contribution to the early development of atomic energy can never be sufficiently realized,' emphasized Sir Christopher. The quality of the uranium initially produced gave cause for great anxiety on account of its extreme brittleness, and he recalled how the first sample of it he was shown was dropped on the floor and broke! However these difficulties disappeared as the full scale processes were got under control and the necessary purity achieved.

HINTON
we had to think for ourselves

In all of this the small staff at Risley were feeling the immense difficulties of starting an organization from nothing. No files of drawings of previous plants were available to use and adapt—every detail of their plants had to be designed on a clean sheet of paper. Engineering standards had to be decided and kept to. And on top of all these difficulties and uncertainties was the problem of the hazard of uranium, by far the most toxic material handled on such a scale in this country up till then. The first bars were finished on October 19, 1948, two and a half years after the offices had opened at Risley. 'A creditable performance,' said Sir Christopher, 'particularly as we were a new organization with no business connexions and most manufacturers thought there was no long term future for us. I remember with gratitude the small number of firms which stood by us and were ready to do anything we asked them.'

Referring to the design of the experimental reactor at Harwell he commented that because of lack of experience they had to stick closely to the scientists' requirements. This made design and construction more difficult than it need have been. 'The great art of engineering is to know how far away from what scientists say is essential you can in fact get.'

Sir Christopher revealed that he proposed to design a reactor to generate useful quantities of heat, cooled by gas under pressure, as early as 1948, but this suggestion was turned down because of the urgent need for plutonium. So they had to proceed to meet the plutonium requirement by the construction of reactors cooled by atmospheric air.

Windscale doubts Several modifications of the original design were necessary; when the biological shield was nearly completed and the construction of a chimney had started it was learnt that American experience had shown that the products of combustion in the event of damage to a fuel element were of larger particle size than had been anticipated and might fall out on the factory site and the surrounding land. An air filtration plant had to be hurriedly provided for the top of the chimney, construction having advanced too far to put it anywhere else, and provision had to be made to detect failure of fuel elements in the very early stages. It was decided to insert a moving monitor apparatus into the back of the reactor, which would sample rows of the 3,000 channels in turn. This meant departing from the basic conception of having no moving parts and the decision to install it was a difficult one to make. 'We ultimately took this decision only a week before the reactor started up,' said Sir Christopher, 'after spending miserably uncomfortable hours observing the behaviour of the equipment from inadequate shelters in the discharge duct while the blowers worked on full power, drenching us with water from the canal and exposing us to an air flow of hurricane force.'

Difficult decisions had also to be made about the graphite structure for the Windscale pile. When design was well advanced it was found that blocks of the required size could not be obtained. After a lot of work had been done the second design also had to be scrapped when information became available which made

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fruits of research

The fruits of research are actual achievements in the field. With Atomic Power Lubricants, Shell have developed a range of petroleum products which are extremely resistant to radiation. This has put Shell right in the forefront of a very specialised sphere—the application of oils and greases to nuclear power plants.

The A.P.L. range was developed at Thornton-le-Moors Research Centre, Cheshire, using Shell's own cobalt source of irradiation. Meanwhile research continues. Today, at Thornton, a staff of 900—chemists, physicists, statisticians, engineers—are employed directly on research projects, pre-eminently among which are lubricating oils for engines and industry generally. The development of A.P.L. is only a beginning and only one of the many lubricating problems tackled at Thornton.

SHELL

The Shell A.P.L. range is further proof of Leadership in Lubrication.

it clear that the graphite would grow under irradiation and eventually prevent discharge of the fuel elements—possibly after only five years of operation.

Violent nitration danger One of the most serious problems of all was posed by the plutonium extraction plant. It had always been realized that there would be a small carry-over of solvent with the aqueous phase—a concentrated solution of nitric acid containing the fission products—from the first solvent separation column. But experimental work had apparently shown that violent nitration of the solvent in the highly active liquor storage tanks could not take place.

This work—on which the design of the plant had been based—was only proved to be incorrect about a fortnight before it was due to go into operation. 'Of all the major unexpected difficulties that we faced in the early years of the atomic energy industry, I believe that this one threatened our programme most. It really took my breath away,' said Sir Christopher. It was solved by the discovery that if the aqueous effluent from the first extraction stage was evaporated down to a quarter of its initial volume as it left the column, the small quantity of solvent carried over was gently destroyed. Stainless steel evaporators were hurriedly removed from another plant and installed, and the plant went into operation on time.

'The major problems of the early years,' concluded Sir Christopher, 'arose from the fact that we were a small organization working against an almost impossible timetable in a field in which we had incomplete knowledge. We had to press on to meet the target date for the production of plutonium. If we were wrong we might fail to meet that date, but if we waited till all was clear there was no hope of meeting it.'

Ships—heavy water?

Enriched fuel is of supreme importance to the future of marine reactors. Failing this, the development of a heavy water moderated gas cooled reactor for a 22,000 s.h.p. 60,000 ton d.w. tanker should be pressed forward urgently, said Dr T. W. F. Brown, Director of Pametrada Research Station, speaking to the Institute of Marine Engineers on March 6. He reviewed the choice of reactors for marine use and commented that all but the established technologies are ruled out for years to come. The PWR is suitable for ship use, but may be uneconomic and almost in one jump has reached the limit of its potentialities. The best answer seems to be a Calder Hall type reactor using slightly enriched fuel. His paper included a study of a possible heavy water moderated reactor on the Russian model. This would have the advantage of using natural uranium. High enrichment does not appear necessary, as even with natural uranium the excess reactivity is quite high. The main problem is to maintain the moderator, which absorbs 7 pct of reactor heat, at a low temperature, though this has the defect of requiring low inlet coolant temperature. There is also the worry of preventing loss or contamination of the expensive heavy water.

Among general problems associated with nuclear propulsion is the weight of the biological shield. It is imperative that this should be reduced by using laminated shields of lead, steel and water. Considerable research is required on this subject, emphasized Dr Brown. Composite shielding, consisting of concentric rings of steel plate, would represent very good armour against collision damage.

BROWN
PWR can go no further

Oil will be dearer Enriched fuel is clearly of supreme importance, he said, whether graphite or water moderators are used. The alternative is a heavy water moderated gas cooled reactor, although this would introduce many new problems of its own. Future costs for nuclear propulsion will be much lower than those arising from the burning of hydrocarbon fuels, which will become scarcer and much more expensive with the passage of time.

Dr Brown concluded by looking forward to the possibility of thermonuclear propulsion. 'In this case,' he commented, 'a ship would be floating on an unlimited store of deuterium.'

In the discussion following the lecture, Dr J. E. Richards, Harwell, speaking for Dr Livingstone Smith, Director of the British Shipbuilding Research Association, complained that not enough attention is being given to size. 'We must keep sight of small sized ships,' he said. Another speaker expressed the view that thermonuclear fusion might eventually be the answer for small power reactors as well as big ones. Criticism of the graphite moderated plant and support for Dr Brown's view of the possible importance of heavy water moderated reactors came from Captain Farquhar-Alken, of Hatton Vickers Nuclear Engineering Co, who urged that a government programme for this should be pressed forward. Another speaker criticized the AEA for withholding useful information on marine propulsion on the grounds of commercial security, and the fear was also expressed that it would be difficult to get the government to carry out development work directed exclusively to merchant ship use. There was general agreement that exact costs are difficult to arrive at at this stage, and that much useful design information, especially on fuel element life, is necessarily slow in accumulating.

Ships—graphite?

There might well be a price break through in the cost of enriched uranium at any moment, and this is one of the main arguments for starting construction on a merchant ship using slightly enriched fuel in a Calder Hall type plant, and getting it to sea as soon as possible. This opinion was expressed by W. R. Wootton of the Babcock & Wilcox Ltd atomic energy department, in a recent paper on nuclear propulsion of merchant ships, to the Scottish branch of the Institute of Marine Engineers. 'Nuclear propulsion is coming, and is coming to stay,' he said. The country with the earliest nuclear merchant ships afloat would gain valuable experience and be creating important precedents in the matter of marine laws and regulations.

Adaptation of the Calder Hall type reactor is technically feasible and there seems to be no insuperable engineering problems in the design of one for a 25,000 h.p. 60,000 ton d.w. tanker. Slight enrichment of fuel, which has a profound effect on size, will be necessary, and the cost of this remains doubtful. But however much the attempts of foreign countries 'to centrifuge enrichment' might be decried there remains the feeling that basic prices might soon be reduced. This confidence in the probability of a price reduction is already making potential customers for British type nuclear plant ask for a design based on enrichment. It is one of the several arguments in favour of getting a nuclear ship afloat now although it might currently be uneconomic.

Attention must be paid to the cost of carrying the biological shield, and he suggested that a more expensive shield like steel shot concrete of less total weight would be worth while.

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NAMES IN THE NEWS

J. ALBERTINI

G. C. FAIRBANKS

A. RUBACH

A. E. GRIMSDALE

Mr Gordon Grant CB, an under-secretary of the Board of Trade has been appointed Comptroller-General of Patents, Designs and Trade Marks as from March 3. He succeeds **Mr J. L. Girling** who has retired.

Mr A. C. Yeates has become chairman of Crossley Premier Engines Ltd in succession to the late Sir Kenneth I. Crossley, Bt.

Following the recent announcement of collaboration between Ruston & Hornsby and J. L. Kier to design and develop small nuclear power stations, **Mr John Albertini,** a chief sales executive, is relinquishing certain duties in order to give his attention to this development. He will also be responsible for the promotion of Ruston gas turbines in the USA.

Mr E. E. R. Fuchs has joined Rustons as personal assistant to sales director Mr T. L. Kendall.

Mr F. J. Lane has left his post of chief transmission engineer with the CEGB in order to join Messrs Preece, Cardew and Rider, the consulting engineers.

Kelvin & Hughes (Industrial) Ltd, have appointed **Mr W. Roddis** as representative for the East and West Ridings of Yorkshire, North Lincolnshire and North Derbyshire. He replaces **Mr J. Illingworth.**

Deputy general manager of Elliott Brothers (London) Ltd. **Mr G. C. Fairbanks** has now been appointed a director of the company. Mr Fairbanks joined Elliotts in 1930.

Dr John Douce of Manchester University has been engaged by Servomex Controls Ltd as a consultant on problems in the fields of non-linear control systems, and systems subject to random fluctuations.

Mr A. E. Grimsdale, formerly manager, home sales, of Metropolitan-Vickers Electrical Co Ltd has now been appointed director and commercial manager. He is already a director of Metropolitan-Vickers Electrical Export Co.

The American firm of Ionics Inc have elected **Wayne P. Brobeck** as vice president in charge of government contracts and nuclear activities.

Mr H. Sellars has taken up the post of commercial manager with Livingston Laboratories Ltd. He was formerly sales manager of Marconi Instruments Ltd.

New chief buyer for the instrument division of George Kent Ltd is **Mr W. T. H. Carter.**

Mr A. Rubach has become managing director of the newly formed Penco Research & Development Co Ltd. Mr Rubach was previously head of the experimental engineering department at the GEC Applied Electronics Laboratories.

The death occurred in February of **Mr H. T. Eatwell,** director and joint deputy chairman of G. A. Harvey & Co (London) Ltd. Mr. Eatwell joined the company in 1929 and became a director in 1937.

CATALOGUES & BULLETINS

Inexpensive, portable atomic laboratory for use in colleges and small research laboratories is now available from the Nucleonic Corporation of America and described in their bulletin N7. Outfit includes scaler-ratemeter, beta-gamma geiger tube and cobalt-60 beta source.
Tick **No 138** on reply card

Profusely illustrated booklet from Versil Ltd describes their glass fibre thermal insulation widely used in conventional power stations, and which has now been accepted by the UKAEA for use in atomic energy work.
Tick **No 139** on reply card

Indicators for precision setting of rotary controls, valves etc are described in booklet from the Clayton Engineering Company.
Tick **No 140** on reply card

Leaflets issued by Shandon Electronics Ltd illustrate the uses of the *Rapikon* electronic chassis assembly system. Working on the slotted angle principle, it is claimed that the most complicated electronic chassis can be made in a matter of minutes with only a screwdriver.
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Book list from the Consultants Bureau Inc of New York gives details of recently translated Russian works including a 200 page book entitled *Physics of fission,* and collected papers on isotope production and high intensity gamma systems.
Tick **No 142** on reply card

Three-way diaphragm valve and a range of stainless steel fittings are described in leaflets from Talbot Stead Tube Co Ltd.
Tick **No 143** on reply card

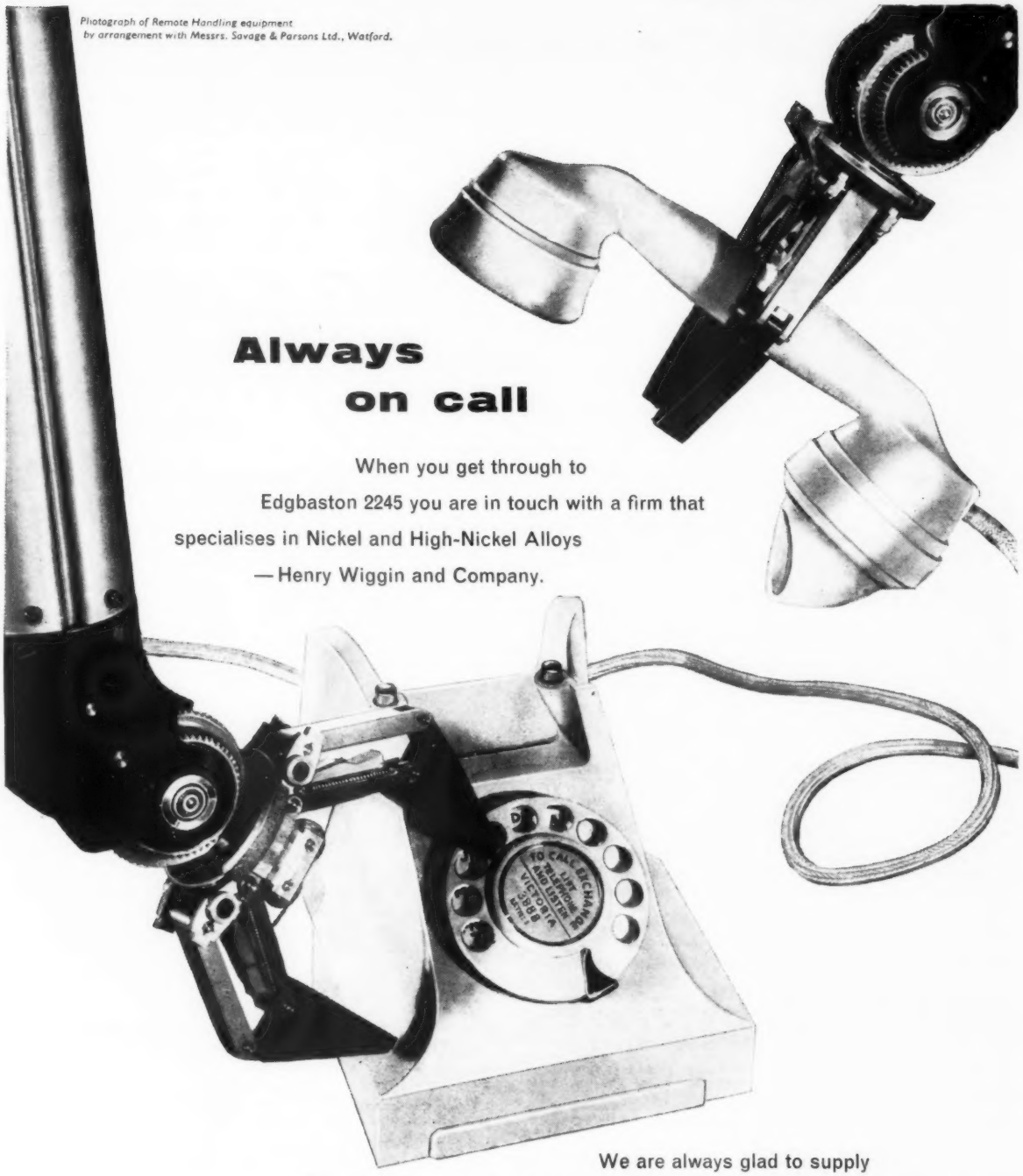
Geared motors and speed reducers of all kinds are shown in leaflet from Electropower Gears Ltd.
Tick **No 144** on reply card

Heat insulating, refractory, corrosion-resistant and quick drying concretes together with their recommended mixes are dealt with in 32 pages from Lafarge Aluminous Cement Co Ltd.
Tick **No 145** on reply card

Data sheet from Black Automatic Controls Ltd describes their present range of solenoid gas valves.
Tick **No 146** on reply card

Pressure and vacuum switches for most industrial purposes are listed in a booklet from Londex Ltd.
Tick **No 147** on reply card

First issue of Constructors John Brown house magazine describes the lifting of the Calder Hall heat exchangers. Complete operation took 22 days but actual lift approximately one hour.
Tick **No 148** on reply card



Photograph of Remote Handling equipment by arrangement with Messrs. Savage & Parsons Ltd., Watford.

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Reports are also available in the United States, from the USAEC depository libraries, a list of which will be found in NUCLEAR SCIENCE ABSTRACTS. Reports for sale may be purchased in the United States from: Sales Section, British Information Services, 30 Rockefeller Plaza, New York 20, N.Y.

AERE Harwell

The tensile properties of uranium from room temperature to 600°C. *N. H. Hancock.* (March 23, 1953. 23 pp) AERE M/R 1156 4s*

A solid particle activity detector. *A. E. Herriott.* (Aug 4, 1954. 33 pp) AERE RE/R 1492 6s*

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Effect of mismatch in R.F. feedback systems. *L. B. Mullett, R. B. Harvey.* (Oct 20, 1955. 17 pp) AERE GP/R 1741 3s*

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The spectrographic analysis of high purity lithium compounds. *R. V. Jury.* (Jan 1956. 8 pp) AERE C/R 1871 1s 9d*

Effective cross section data for thermal reactor calculations. *C. G. Campbell, R. G. Freemantle.* (July 1957, 6 pp) AERE RP/R 2031 (Supplement 1)

Resonant cavity measurement techniques at 400 Mc/s. *W. Boyd.* (Aug 1957. 16 pp) AERE GP/R 2184 3s*

Gas scattering in proton synchrotrons with variable rate of acceleration. *R. J. B. Hadden.* (Aug 1957. 22 pp) AERE GP/R 2189 3s 6d*

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The lanthanum fluoride coprecipitation method for the determination of plutonium. The efficiency of precipitation of the lanthanum carrier fluoride. *R. G. Monk.* (June 1950. 6 pp) AERE C/R 2382 1s 9d*

The distillation of liquid metal (bismuth) reactor fuel. *F. S. Martin, R. E. Brown.* (Sept 1957. 17 pp) AERE C/R 2391

The diffusion length of thermal neutrons in Portland concrete. *R. A. Dugdale, E. Healy.* (Oct 1957. 5 pp) AERE R/R 2403 1s 9d*

Some worked examples in radiation shielding. *C. C. Horton.* (April 18, 1955. 11 pp) AERE RS/L 3A 2s 6d*

Reactor fuel cycles and neutron economy. *F. W. Fenning* (March 8, 1956. 20 pp) AERE RS/L 21 3s 6d*

Apparatus for handling fluorine in the laboratory. *C. J. Mandleberg, H. K. Rae.* (Feb 1953. 6 pp) AERE C/M 172 1s 9d*

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The surface activity of various uranium and uranium alloy ingots. *J. Redfearn, B. W. Mott.* (1949. 5 pp) AERE M/M 12 1s 9d*

The excess reactivity controlled by a single, central control rod. *J. D. McCullen.* (1951. 5 pp) AERE R/M 3 1s 2d*

A two-group computer programme for two-zone spherical reactors. *W. G. Davey, J. R. Harrison.* (Oct 1957. 14 pp) AERE R/M 146 2s 6d*

The temperature coefficient of reactivity due to thermal expansion of a reflected spherical core. *J. Codd.* (April 1954. 15 pp) AERE RP/M 40 3s*

Industrial Group

Monitor for water vapour in carbon dioxide. *C. D. Reid, K. W. Paget, J. W. Hill.* (Dec 1957. 17 pp) IGR R/CA 201(D)

Treatment and disposal of gaseous, liquid and solid radioactive wastes: information bibliography. (Nov 1957. 34 pp) IGRL IB/R 28 3s 6d*

APRIL DIARY

ICE Institution of Civil Engineers. IMechE Institution of Mechanical Engineers. IEE Institution of Electrical Engineers. IChemE Institution of Chemical Engineers. IP Institute of Physics. PS Physical Society. SCI Society of Chemical Industry. IM Institute of Metals. IMet Institution of Metallurgists. IMM Institution of Mining and Metallurgy. IPE Incorporated Plant Engineers. SIT Society of Instrument Technology. Brit/IRE British Institution of Radio Engineers. RSH Royal Society of Health. IR Institute of Refrigeration.

TUESDAY 1

LONDON IR An experimental study of the use of mixed refrigerants for obtaining cooling over a temperature range *G. G. Hasleden, L. Klimek* 5.30 at The Junior Institution of Engineers, 14 Rochester Row, SW1

LONDON IEE Discussion: Economic aspects of electrical engineering 6.00 at the Institution

LONDON IPE A small generating station and its relation to process steam demands *B. E. A. Vigers* 7.00 at the Royal Society of Arts, John Adam St, WC2

MONDAY 7

DUNDEE IPE The uses of electronics *R. B. Smith* 7.30 at Mathers Hotel

TUESDAY 8

LUTON IEE Transistor amplifier circuits *W. A. Thorpe* 6.00 at the Staff Canteen, D. Napier and Son, The Airport, Luton

WEDNESDAY 9

LONDON IMechE Discussion: The combined nuclear/fossil fuel cycle 6.00 at the Institution

BRISTOL IPE The plant engineer and work study *H. A. Gomm* 7.15 at the Grand Hotel

THURSDAY 10

DERBY IMechE Nuclear propulsion applications *D. J. Allen-Williams* 7.15 at the Art Gallery (Strand entrance)

CAMBRIDGE PS Conference on Nuclear Physics at the Cavendish Laboratory continuing to the 11th

WEDNESDAY 16

LONDON IEE with BNEC Operational experience: Calder Hall *K. L. Stretch* 5.30 at the Institution

LONDON IP Heat transfer problems of nuclear reactors *W. B. Hall* 6.00 at the Institute, 47 Belgrave Sq, SW1

LONDON Instruments, Electronics and Automation Exhibition opens at Olympia continuing to the 25th

TUESDAY 22

CARDIFF IPE Effects of steam peaks *E. G. Ritchie* 7.15 at the South Wales Engineers Institute, Park Place

WEDNESDAY 23

LONDON BritIRE Measurement of the frequency response of a nuclear reactor *R. B. Cox, D. Harrison, R. B. Stevens* 6.30 at London School of Hygiene and Tropical Medicine, Gower St, WC1

LONDON IMechE Discussion: Teaching the fundamentals of automatic control 6.00 at the Institution

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Photographs of the I.D.L. GammaSwitch and the new I.D.L. Scintillation Counter type 700 (specially shielded for clinical work), together with descriptions of other I.D.L. exhibits, will be found in the exhibition preview in this issue of NUCLEAR POWER

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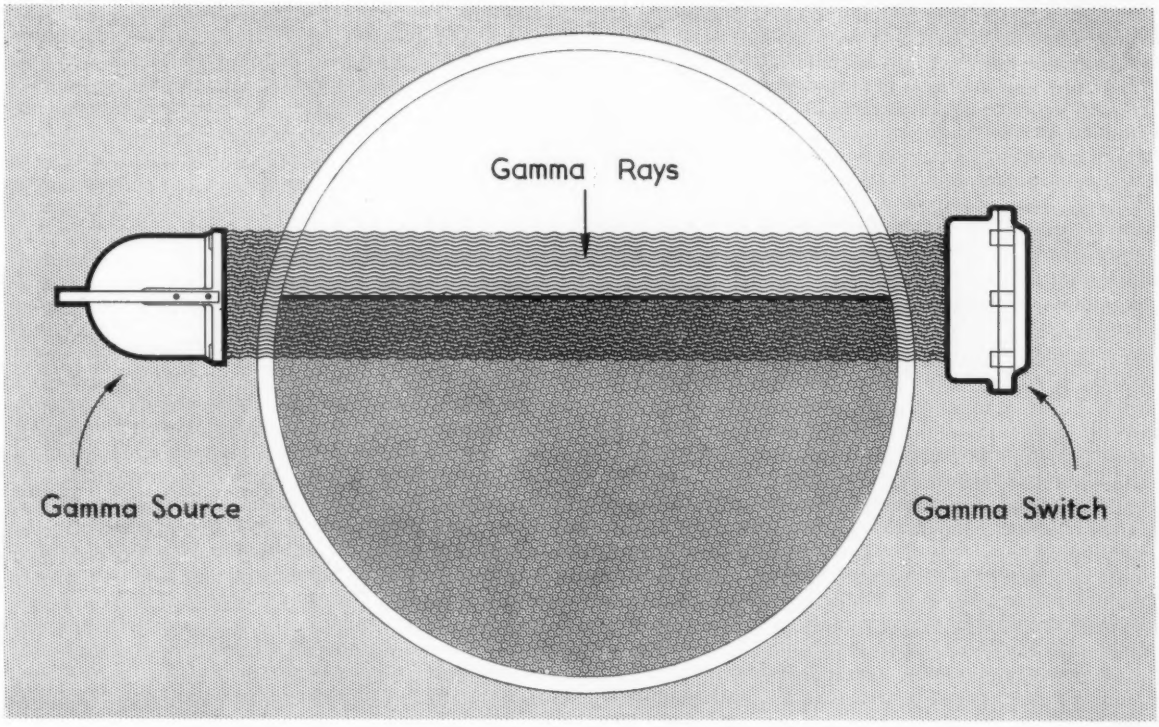

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PATENTS

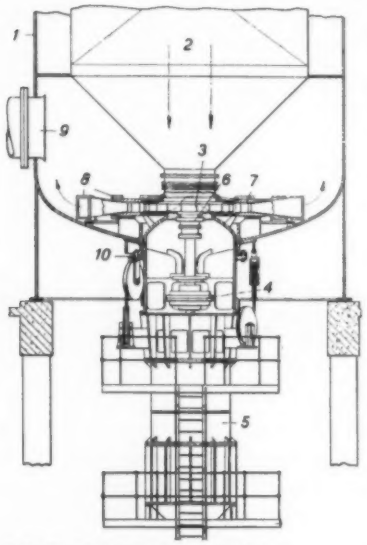
Troglodyte

Power reactors, whether gas-cooled or water-cooled, involve pressure vessels in very thick materials and this is considered by these inventors a serious inconvenience. To get over this, the Swedish General Electric Co propose installing a vessel of comparatively small thickness in a hole excavated in a solid rock foundation which would take the main bursting stresses. The excavation would of course be lined with smooth concrete and water or other fluid medium could be used for transmitting pressure between the shell and the excavations. Means are also described for taking care of thermal expansion. In one application, the pressure shell extends above the reactor proper to include the loading area.

785,528 Nuclear reactor plant *Allmanna Svenska Elektriska Aktiebolaget* Appn: July 20, 1956 Pubd: Oct 30, 1957

On the inside

Hunterston is the only one of the new British nuclear power stations that is using centrifugal blowers for gas circulation and the reasons for General Electric's choice are put forward in this patent. Owing to the relatively small



789,482 CENTRIFUGAL BLOWER

1	Boiler shell	6	Shaft seal
2	Tube elements	7	Diffuser
3	Impeller	8	Diffusion funnels
4	Coupling	9	Duct to reactor
5	Motor	10	Gas-tight joint

pressure rise needed across the blower in these plants only one stage is needed and the centrifugal type would seem to be very suitable. The static pressure is however very high and the normal type of diffuser scroll casing is considered by these inventors fundamentally unsuitable to withstand this. The GEC designers have therefore proposed to get over this difficulty, while retaining a centrifugal impeller, by installing the blower actually inside the boiler. By this means, the diffuser casing need only be capable of withstanding the differential pressure and can therefore be made in comparatively light material. Furthermore, since there are now no restrictions on size, the impeller and diffuser sections can be very large, thus contributing to efficiency. The arrangement which is to be adopted at Hunterston is probably much as described in this specification. Note how the motor is outside the pressure circuit. The invention also covers axial- and mixed-flow impellers.

789,482 Improvements in or relating to nuclear reactor arrangements. *General Electric Co Ltd* (*Inventor: P. A. Lindley*) Appn: Dec 2, 1955 Pubd: Jan 22, 1958

Safe runaway

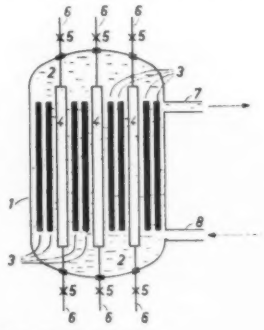
In a water boiler or solution reactor, a super-critical mass of fissionable material has to be added to the core to make allowance for burn-up, poisoning, neutron absorption etc. This could make a runaway particularly dangerous, and North American Aviation have devised a simple means of eliminating this hazard in their reactor design. The effect of the reactivity exceeding unity is a sudden increase in the number of gas bubbles produced by decomposition of the solvent due to irradiation. The solution suddenly expands and surges out of the containment vessel. The overflow system proposed here consists of a vessel, connected to the core by a wide horizontal duct and separated from it by reflector material, to collect the overflow solution and gas, and a bubble pump to return it to the core when the excess reactivity has subsided. To ensure that the mass of fissionable material left in the core after the surge ejection does fall below criticality, the size of the overflow vessel has to be carefully chosen.

783,400 Improvements in or relating to liquid homogeneous reactor safety overflow system *North American Aviation Inc.* (*Inventor: I. F. Weeks*) Appn: Feb 20, 1956 Pubd: Sept 25, 1957

Thermo-hetero reactor

Reactors are commonly thought of as either heterogeneous or homogeneous but this is an idea for combining the two, advantages claimed being: better burnup than a pure heterogeneous type, easy control by altering the concentration of the fissionable solution.

According to one embodiment the heterogeneous core—subcritical on its own—is in the form of slightly enriched uranium rods immersed in a moderator of enriched light water. Between the rods are vessels containing the enriched fissionable solution which is circulated through the core. The moderator is also



788,288 BEST OF BOTH

1	Pressure vessel	6	Connexions to fuel process
2	Moderator	7	Coolant outlet
3	Fuel rods	8	Coolant inlet
4	Homogeneous fuel		
5	Valves		

used as coolant, being kept at sufficient pressure to prevent boiling and also to ensure that possible leaks in the liquid fuel vessels do not contaminate the primary circuit.

788,288 Nuclear reactors *Sulzer Frères SA* Appn: Sept 25, 1956 Pubd: Dec 23, 1957

Design for SUSPOP

The difficulty of maintaining the concentration of the fuel constant throughout the reactor vessel is one of the main problems of suspension or slurry type reactors. This is further aggravated by the fact that, to obtain a high thermal yield, a high temperature must be maintained and this promotes settling of the fuel as the carrier viscosity is then low.

The Dutch RCN found that these problems may be largely overcome by the observation of certain principles which they have incorporated into the design of SUSPOP, described in some detail in this patent. In broad outline the principles are as follows: to keep the suspension free of turbulence, the reactor vessel must be designed so that over the greater part of its descent the suspension is conducted by vertical passages or passages of uniform cross-section. Also, although the concentration of the suspension descending through the vertical passages may vary horizontally, it must be constant across any vertical plane in the reactor vessel.

783,985 Process and apparatus for carrying out nuclear fission reactions. *Stichting Reactor Centrum Nederland* Appn: March 8, 1954 Pubd: Oct 2, 1957

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications can be obtained from the Patent Office (Sales Branch), 25 Southampton Street, London, W.C.2. 3/6 a copy (including postage, inland and abroad)

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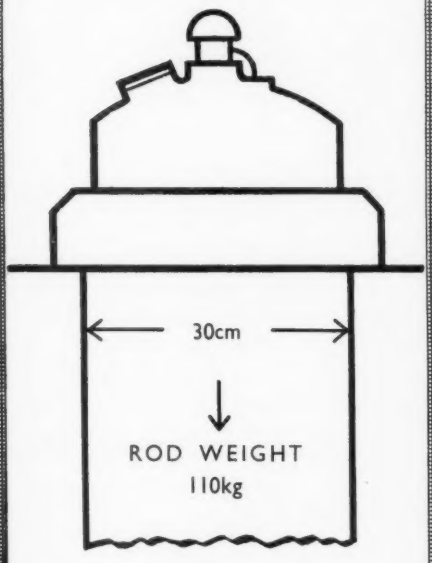

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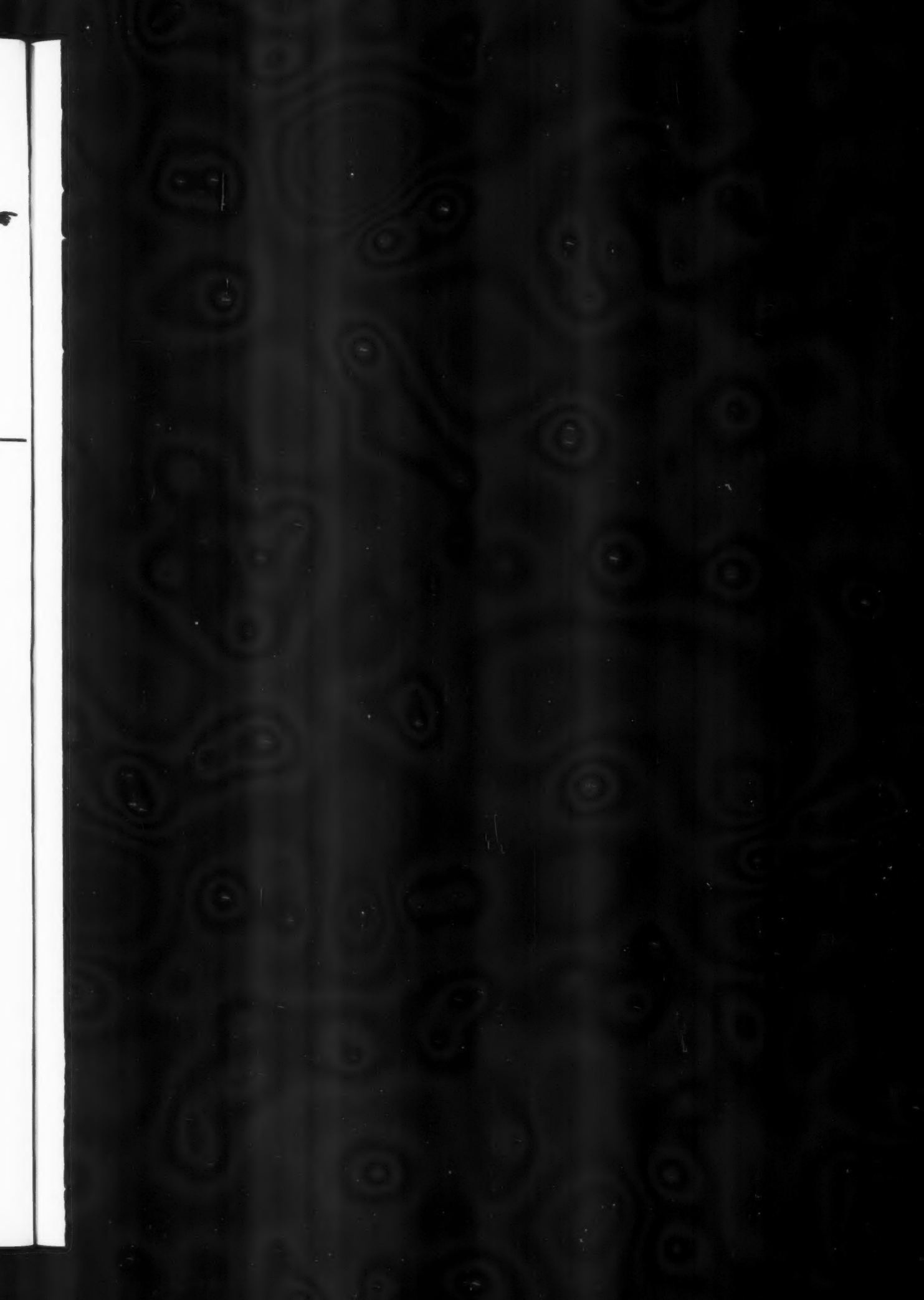

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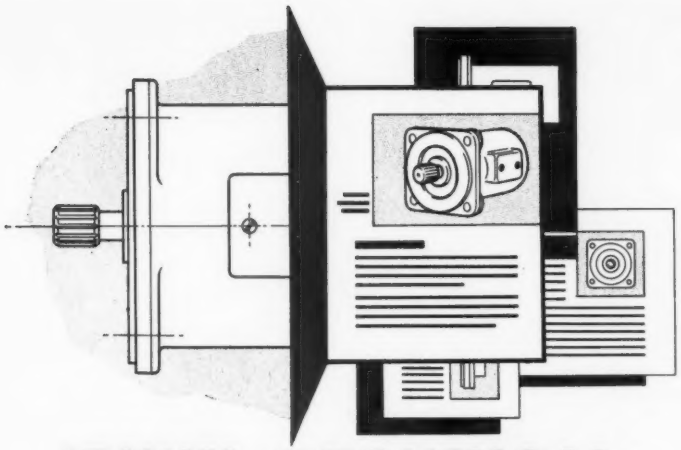

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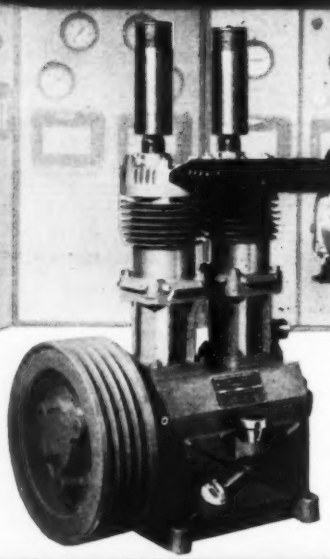

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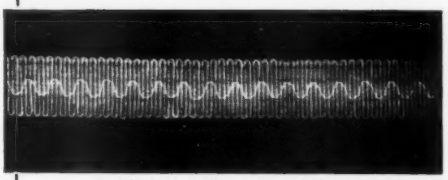

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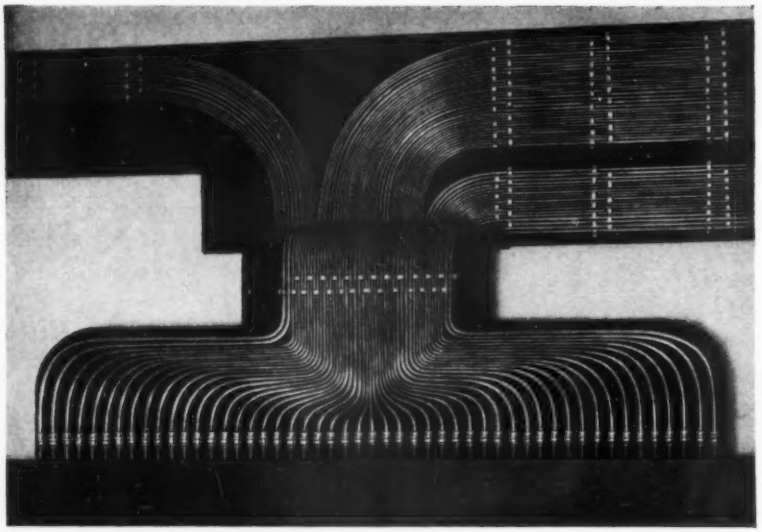

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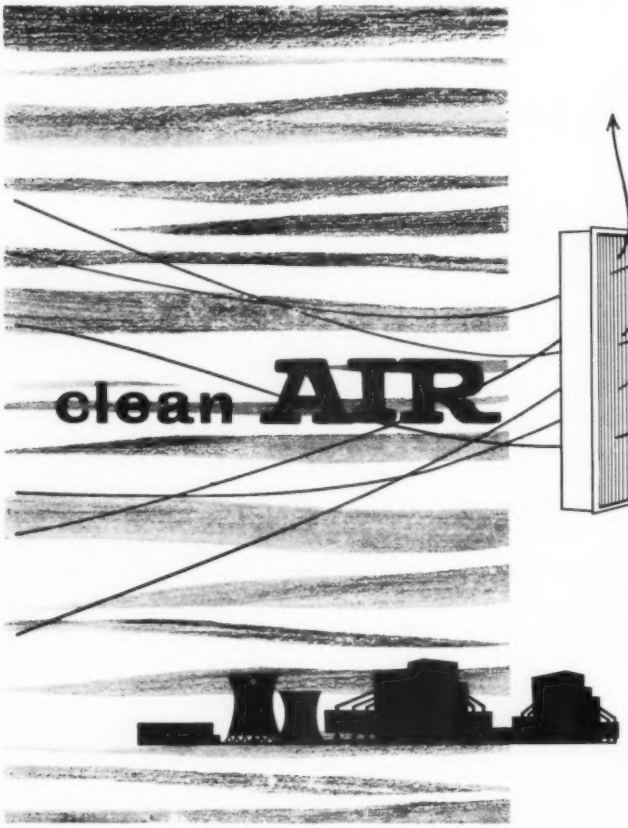

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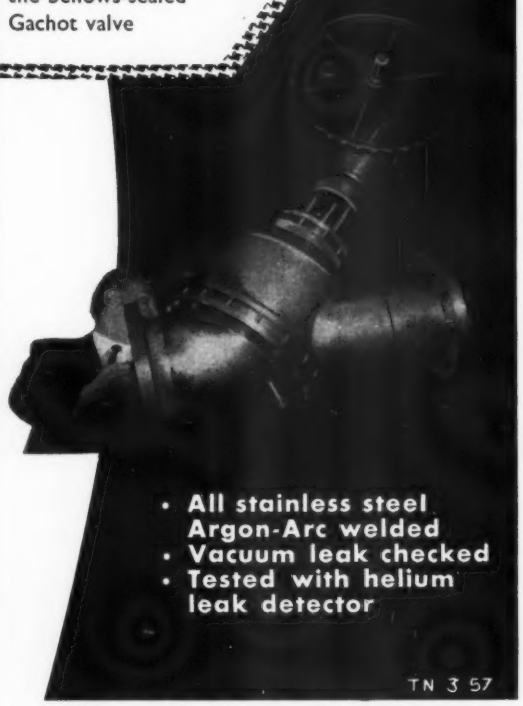

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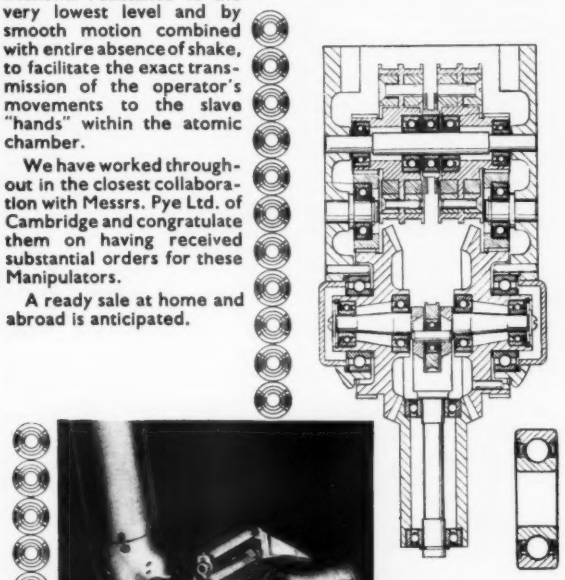

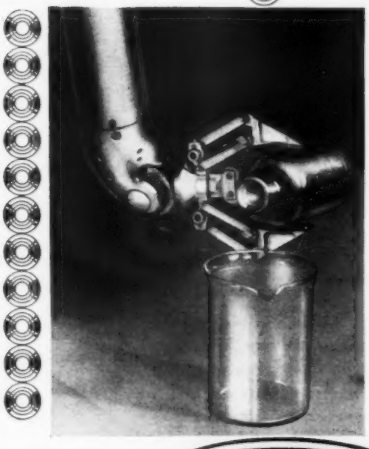

ABOVE Bearing layout for the "wrist" assembly including an enlarged view of one of the shielded ball bearings.

LEFT Slave "hand" grasps and pours contents of bottle.

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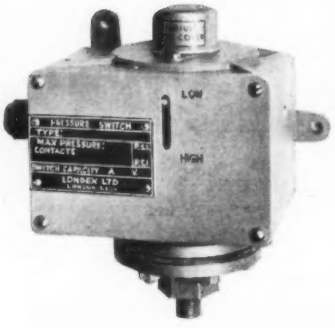

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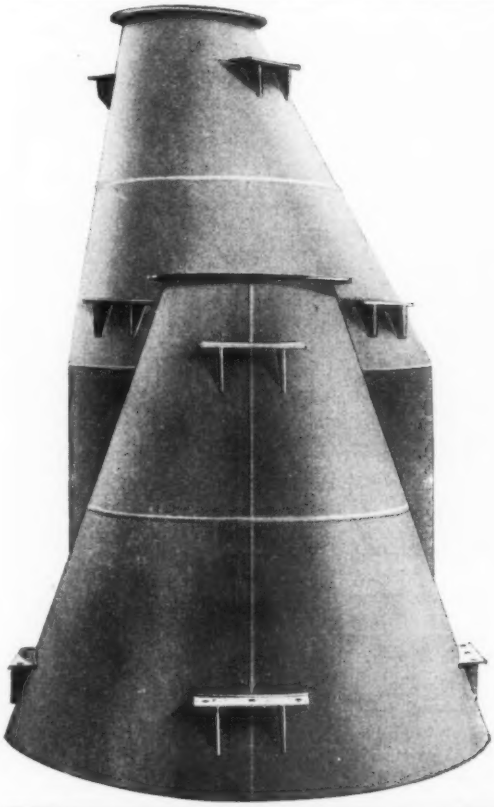

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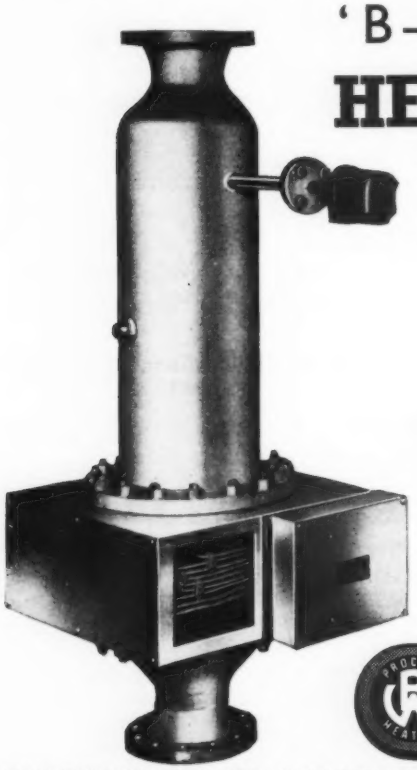

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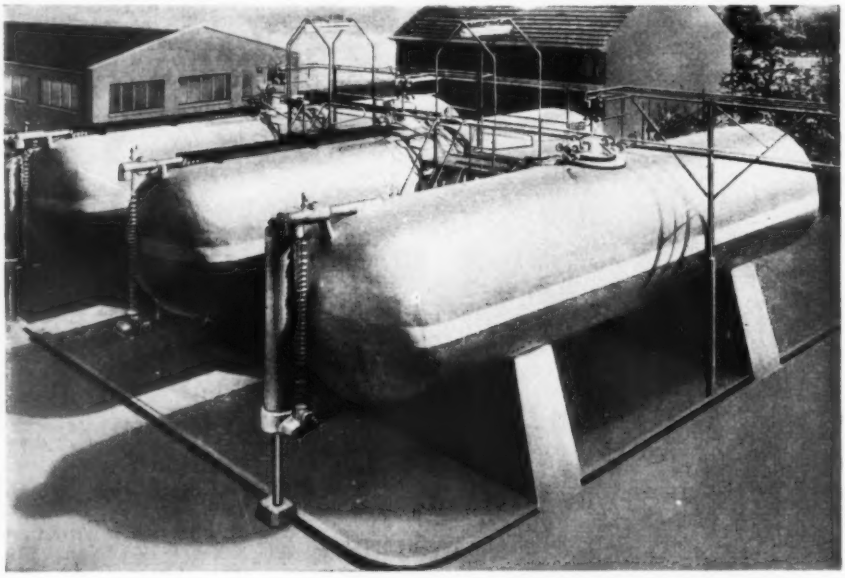

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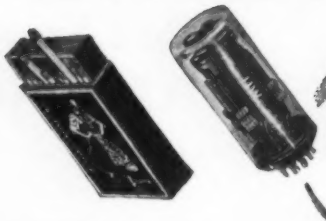

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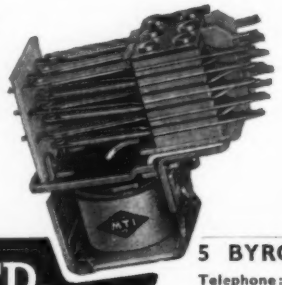

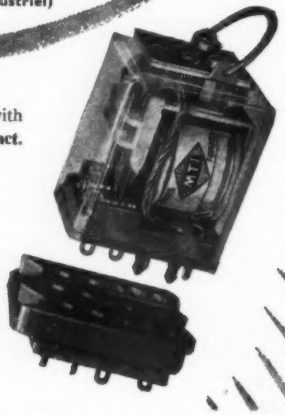

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(Manufacturers and Trade enquiries only)

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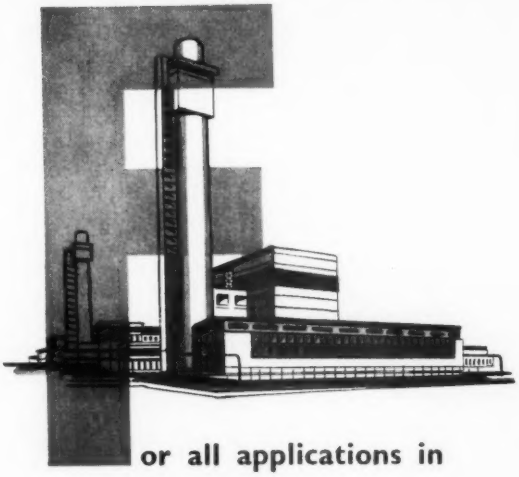

or all applications in Nuclear Power plants . . . . . continue to fit

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bolts, nuts, screws and other fasteners with corrosion, contamination and heat resistant properties.

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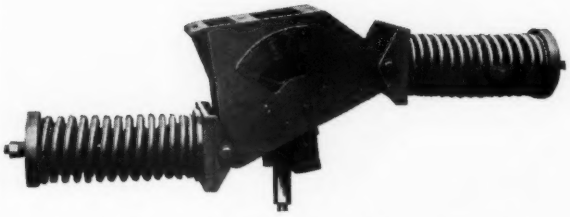
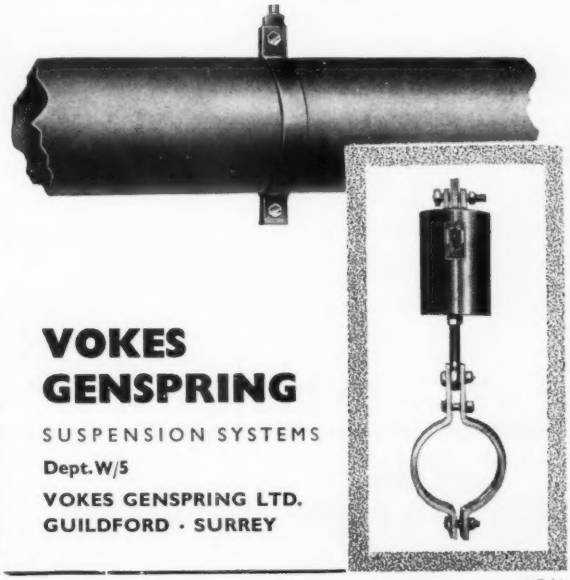
SAFE SECURE SUPPORTS

Flexible Pre-Engineered Pipe Hanging



Piping that moves may well give rise to weight transfer and dangerous stresses at terminal points. Some high temperature pipes need complete support throughout their range of movement and to control vibration, while others need only limited control of vertical movement. In both instances the support provided must be correctly related to the stresses. Scientifically designed and constructed VOKES GENSPRING Suspension systems keep all such stresses safely under control. For uniform support VOKES GENSPRING CONSTANT SUPPORT HANGERS accurately balance the weight of the pipe, allow free non-resonant movement in all "hot" and "cold" positions, so eliminating weight-stress. Made to support loads of up to 30,000 pounds with travels up to 12", they simplify piping design and give the best possible protection to costly equipment. Designed to control vertical movement, VOKES GENSPRING VARIABLE SUPPORT HANGERS (shown below) give a variation of only 4½% of rated capacity per ½" of deflection. They provide a safe and convenient method of support, they are easily installed and may be moved at will for use in alternative positions. Various types are available including special adaptations for low headroom. If you have pipe suspension troubles send for the two Vokes Genspring Catalogues. They give full details of each method and will help you to select the type of suspension most suitable for your particular requirements.



VOKES GENSPRING

SUSPENSION SYSTEMS

Dept. W/5

VOKES GENSPRING LTD.
GUILDFORD · SURREY

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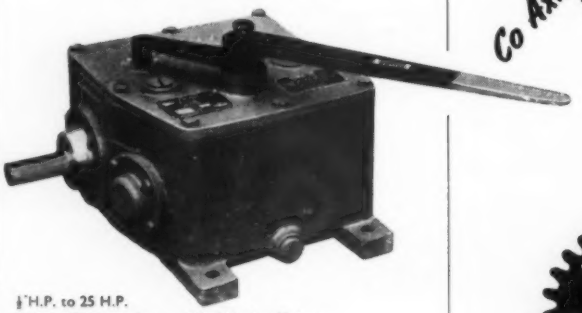
Variable Speed Gearboxes



¼ H.P. to 25 H.P.
Robust Construction — No Friction Drives
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Gear change under load without clutch

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The Positive Answer to Your Drive Problems

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STRATELINE
Fixed Reduction Speed Reducers

Torque range 46 lbs. ins. to 48,000 lbs. ins. Exact ratios to suit your requirements between 3 to 1 and 1,000,000 to 1. Motorised with any make or type of Motor or Non-Motorised. Positive drive in either direction. Reductions up 1,000,000 to 1 obtained in incredibly small space.

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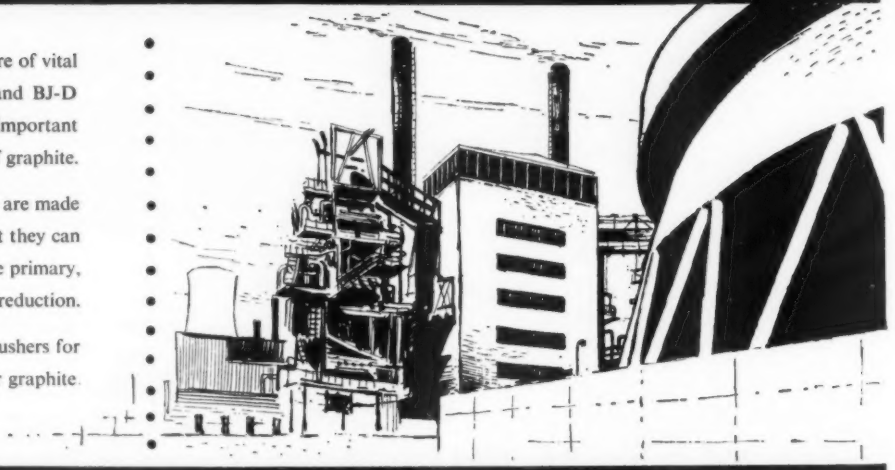
Graphite moderators are of vital importance in thermal reactors and BJ-D Crushing Machines are just as important in the production of graphite.

British Jeffrey-Diamond Crushers are made in a wide range of sizes so that they can be economically employed in the primary, secondary, or tertiary stages of reduction.

Specify BJ-D Crushers for the production of nuclear graphite.



BJD

BRITISH JEFFREY-DIAMOND LTD.
Crusher & Industrial Division
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WF 5015

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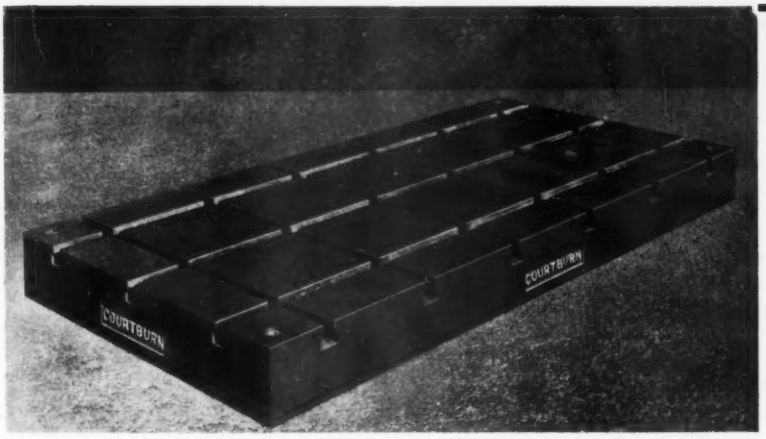

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Courtburn Welding Platens provide a flat surface on which fabrications can be set up accurately.

Three sizes up to 8′ × 4′ are robustly made from finest quality close-grained grey iron.

"T" slots for 1 in. dia. holding down bolts are provided to the pattern illustrated, and there are four socket head cap screws for levelling purposes.

A number of platens may be placed side by side to form any required area of bed plate.

AN AID TO GREATER ACCURACY IN FABRICATING

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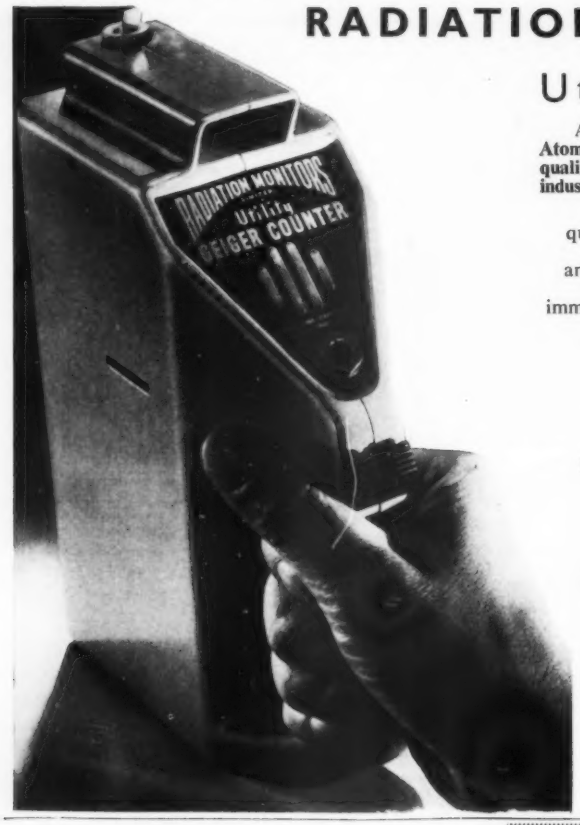
RADIATION MONITORS LIMITED

Utility GEIGER COUNTER



A highly sensitive, portable instrument made under licence from the U.K. Atomic Energy Authority as a general purpose monitor for the detection and qualitative measurement of gamma, hard beta and x-rays in laboratories or industrial premises.

The design employs a specially-produced low-voltage halogen-quenched geiger-mueller tube in a simple integrator circuit developed from that evolved at the Atomic Weapon Research Establishment, and provides three ranges of visual response by flashing neon, together with a loudspeaker count of each ionising event at low radiation and immediate appreciation of any significant flux change at higher intensities.

A convenient personal monitor, the Utility Counter is also suitable for radioactive survey in connection with the location of thorium or uranium ores and is ideal for realistic Civil Defence training, while the provision of a pulse output socket for connection to external circuit, oscilloscope or recording scaler is of particular advantage for demonstrating elementary nucleonics in schools and technical colleges.

Supplied complete with battery pack and comprehensive instruction book covering elementary nucleonics, geiger counter theory, and notes on amateur prospecting. Miniature crystal earpiece on extension lead with jack plug an optional extra.

£10, plus batteries £2 15 3

Principal data:

Size 9 × 6 × 3 inches. Weight 3 lb.
Background count 90 c/min.
Operating potential 400–450 V.
Current consumption ·001 to 10 μA
Battery life exceeds shelf life
Response exceeds 30,000 c/m
Output pulses approx. 1, 15 and 50 volts.

U.K. Distributors: **PROOPS BROTHERS LIMITED**
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pulse amplifier

Pulse Amplifier, Type 1430A is a wide band linear amplifier comprising three units designed for use with fast ionisation chambers, proportional and scintillation counters.

See this and other DYNATRON instruments on STAND 918 at the INSTRUMENTS, ELECTRONICS and AUTOMATION EXHIBITION, Olympia, 16th to 25th April

SPECIFICATION:

Main Amplifier

Input: 100 ohms impedance. Negative polarity.
Gain: Maximum 86dB. Coarse Control: −0 to 20dB. Fine Control: −0 to 20dB in steps of 2dB each.
Integrating Time Constants: 0·08μs to 8μs in 7 steps.
Differentiating Time Constants: 0·08μs to 8μs in 7 steps plus 250μs step.
Output: Positive 50v. for 1% linearity.
Saturation 70v.
Upper Frequency Response: 1·25dB to 1·4 Mc/s. 3·25dB to 2·8 Mc/s.

H.F. Head Amplifier

Input: 10 megohms, 10pf.
Output: Designed to feed into 100 ohm matched cable.
Gain: 31·5dB.
Filter: E.H.T. Filter suitable for voltages up to 3kV.

Cathode Follower

Input: 10 megohms, 10 pf.
Output: Designed to feed into 100 ohm matched cable.
Insertion Loss: 23dB.
Filter: As in H.F. Head Amplifier.

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NUCLEONIC AND ELECTRONIC DEPARTMENT
Dynatron Radio Ltd.,
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Scalers · Pulse Generators · Pulse Analysers · Power Units · Probe Units · Pulse Amplifiers · Instrument Racks

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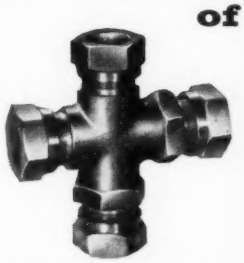
The international pipe couplings of proved efficiency

EQUAL ELBOWS *to suit N.B. sizes ⅛" to 1¼" and O.D. sizes ⅜" to 2"*



EQUAL CROSSES *to suit O.D. pipe sizes ⅜" to 2" and N.B. pipe sizes ⅛" to 1¼"*

ERMETO high pressure couplings have several outstanding qualities, not the least of which is their trouble-free service even in conditions of extreme vibration. Beyond the removal of burrs no work is necessary on the pipe ends. Joints are made in a matter of moments and when required can be broken and re-made any number of times without impairing the pressure tightness. Because of our specialized knowledge we have created a range of fittings to suit almost every conceivable purpose, but we are always prepared to supply fittings to suit individual requirements.

BANJO COUPLINGS *to suit O.D. pipe sizes ⅜" to 2" and N.B. pipe sizes ¼" to 1¼"*

STRAIGHT COUPLINGS *to suit N.B. pipe sizes ¼" to 1¼" and O.D. pipe sizes ⅜" to 2"*

ERMETO

Literature and catalogues gladly sent on request

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● For repeated use up to 1050° C. ● Completely inert to all acids except hydrofluoric.

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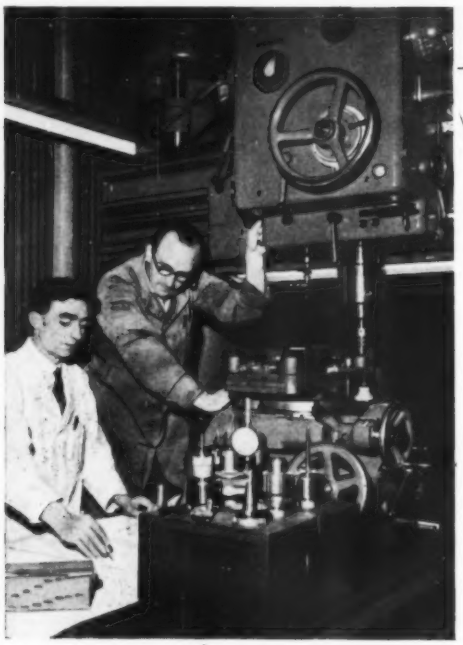

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Constructional Plant Refuelling Unit by Darham, for operation on site at Bradwell.

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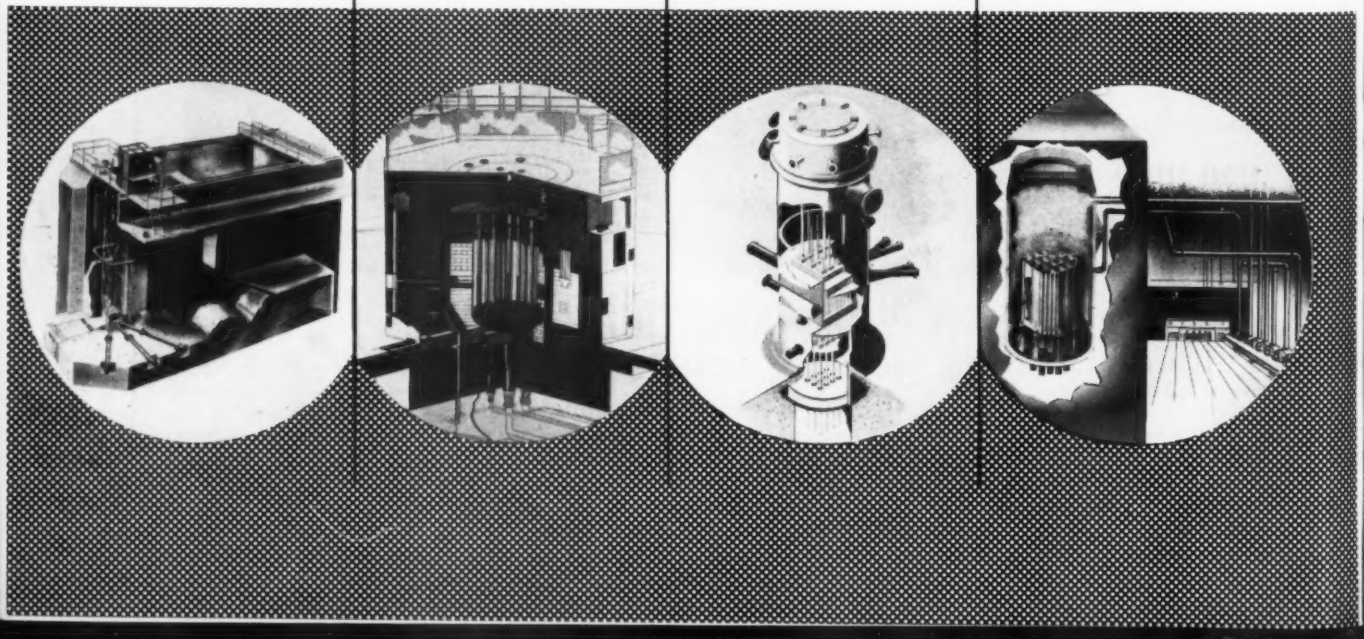
Unlike other builders of nuclear reactors who specialize in specific types — ACF has achieved prominence through diversification. This diversification is a tribute to the range and depth of our scientific, engineering and manufacturing skills. As a result of our field proven designs — today we offer a group of "standard reactors". The ACF Heavy Water Tank Type standard reactor is the direct result of the experience gained with the MIT reactor, the Italian National Committee reactor in Italy and other designs recently completed for government and private organizations. By combining the best features of each of these installations ACF is ready to offer a standard Heavy Water Tank Type research reactor with power levels ranging from 1000 KW to 10,000 KW.

Another standardized reactor is the ACF Light Water Tank Type—based on the best design features of 4 similar units now under construction in the U.S., Holland and Sweden with power outputs ranging from 10,000 KW to 30,000 KW. Used primarily for materials testing and engineering development, these units are further evidence of ACF's established pattern of reliability in reactor design and construction.

Two ACF Power Reactor Designs have recently been completed — one the Boiling Water Reactor Type and the other the Gas Cooled Type. The ACF approach to power reactor construction is based on the use of **proven** engineering and **sound** design to provide the customer with the most economic solution of his problem with **existing** technology.

LIGHT WATER POOL TYPE | HEAVY WATER TANK TYPE | LIGHT WATER TANK TYPE | PROCESS HEAT



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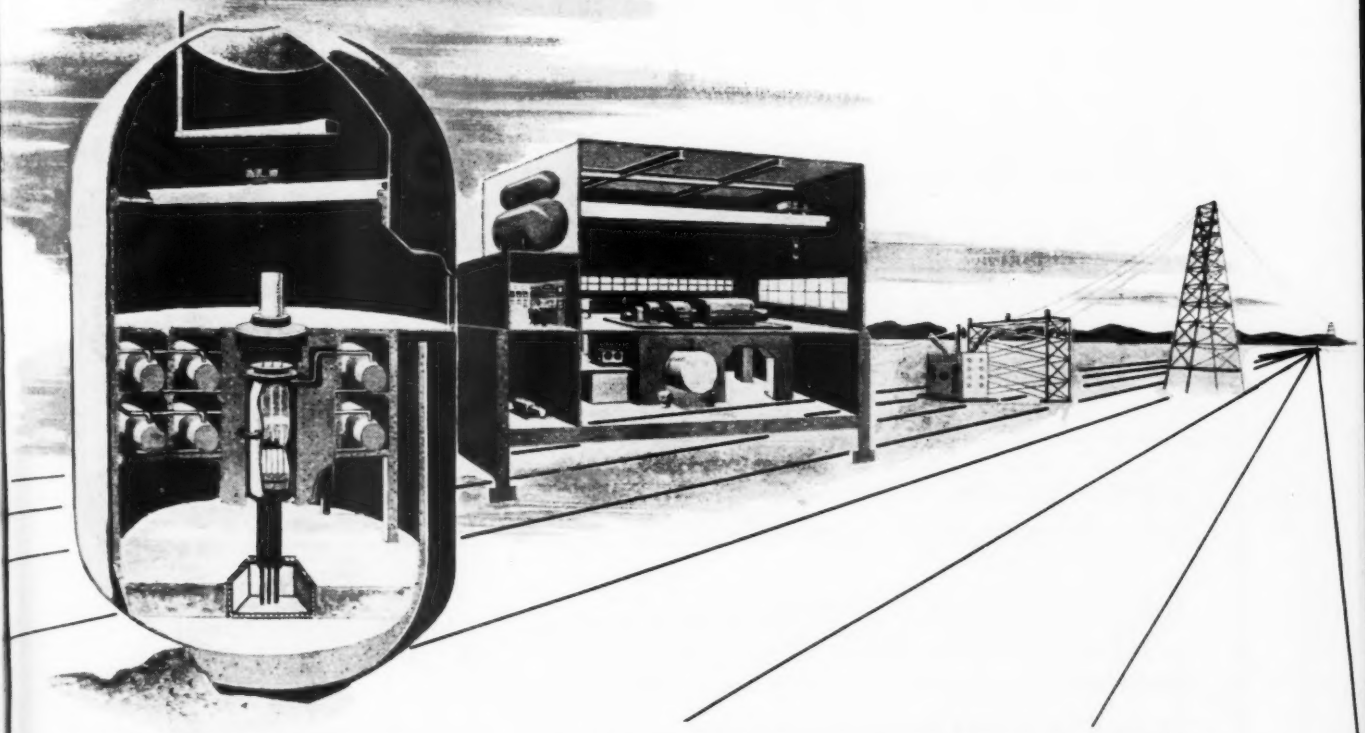
based on experience

Other new design developments at ACF include the Process Heat Reactor and the complete line of Pool Training Reactors as announced recently.
Reactors from a 1 watt trainer to 150,000 TKW power unit have already been designed by ACF. No matter what your requirements are in the area of nuclear reactors, the diversification, experienced personnel and proven designs found at ACF are your best assurance that we have a sound technical and economic approach to your problem. We are free at any time to undertake exploratory discussions. Write to us, or see us at our Booth at the Atom Fair March 16-21.

BOILING WATER POWER REACTOR



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NUCLEAR PRODUCTS–ERCO

Division of ACF Industries Incorporated

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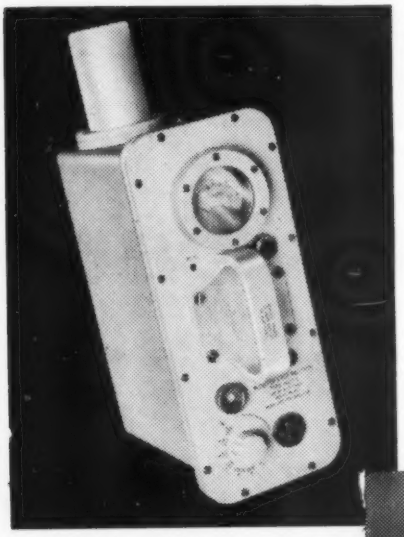

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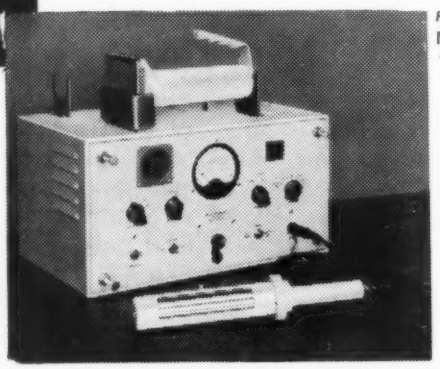
WHERE EVERY NUCLEONIC PROJECT STARTS

FAST NEUTRON MONITOR *Type 1407C*

A self-contained general purpose Fast Neutron Monitor, designed in conjunction with A.E.R.E., Harwell.

- *Meter calibrated 0-4 counts per second*
- *Measurements up to 400 counts per second in 3 decades*
- *Incorporates proton recoil proportional counter*
- *Powered by seven 1.3 volt "Kalium" mercury cells*
- *Fully sealed for operation in unprotected positions*
- *Easily decontaminated and readily transportable*



RADIATION MONITOR *Type BN.110*

Designed primarily for measurement of radiation from contaminated apparatus or surfaces, and personnel monitoring using Alpha and Beta/Gamma Probes.

- *Count rates up to 5000 per second in four ranges using meter indication*
- *Resettable register for low count rates*
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manufacturers of Head Amplifiers

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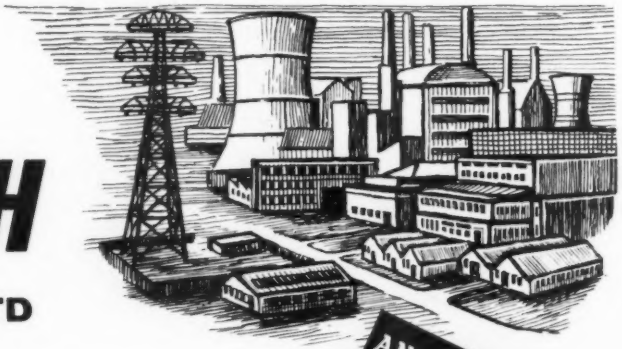

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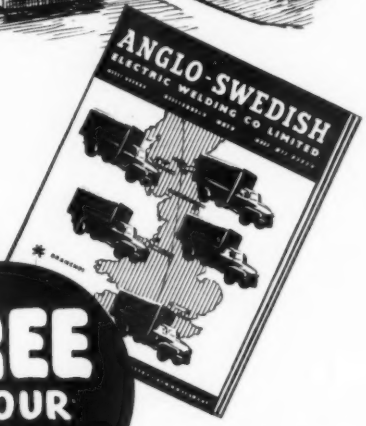

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HEAVY DUTY REMOTELY CONTROLLED POWER OPERATED MANIPULATOR

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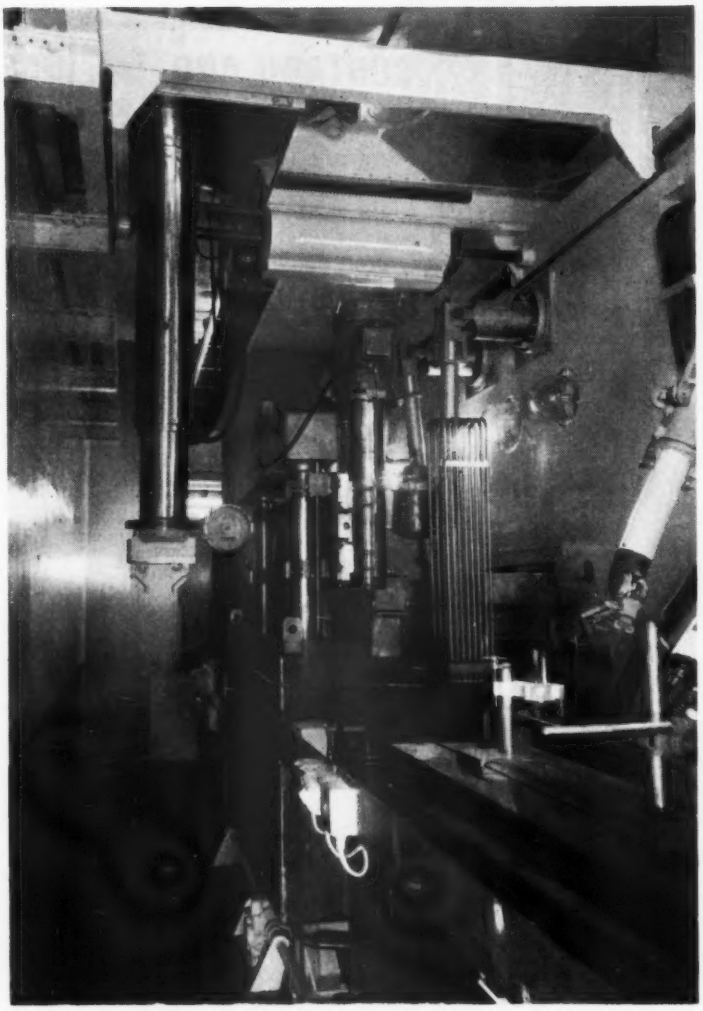

Travelling Manipulator installed in Windscale Laboratory.

featuring the following unique advantages:—

- **CAPACITY**
  will handle greater loads and provide more power than any known similar manipulator.
- **VERSATILITY**
  no less than 12 independently controlled and separately powered motions including 2 Power Take-Off drives for tools and ' heads '.
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  automatic ' feed-back ' of applied effort provides operator with ' feel ' over control and effort, enabling heavy operations to be performed to an accuracy of thousandths of an inch.
- **SIMPLICITY**
  designed and built to precise but rugged standards and very simple to operate, this manipulator requires the absolute minimum of servicing and decontamination.
- **FLEXIBILITY OF INSTALLATION**
  can be remotely controlled from one or more independent ' stations '. Designed to withstand the effects of high level gamma radiations.
- **ADAPTABILITY**
  a range of automatically and remotely interchangeable power tools or ' heads ' is available, including Drilling, Box Spanners, Lifting and Wrist Motion Jaws, Slitting and Grinding, etc.
- **MODEST COST**
  this Manipulator is not an unproven prototype, but has been subjected to the most searching and stringent acceptance tests by the U.K.A.E.A.

We have Designed and Procured:—

IRRADIATED FUEL ELEMENT LABORATORY—WINDSCALE
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BOTH PLANTS CHOSE OUR MANIPULATOR FOR THE REMOTE HANDLING OF RADIOACTIVE RIGS AND FUEL ELEMENTS

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DESIGN HOUSE · THE MALL · EALING · W.5 · Telephone: EALing 9843 and 1942

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EAST 2613-7; 4601-2 *Estab. 1863*

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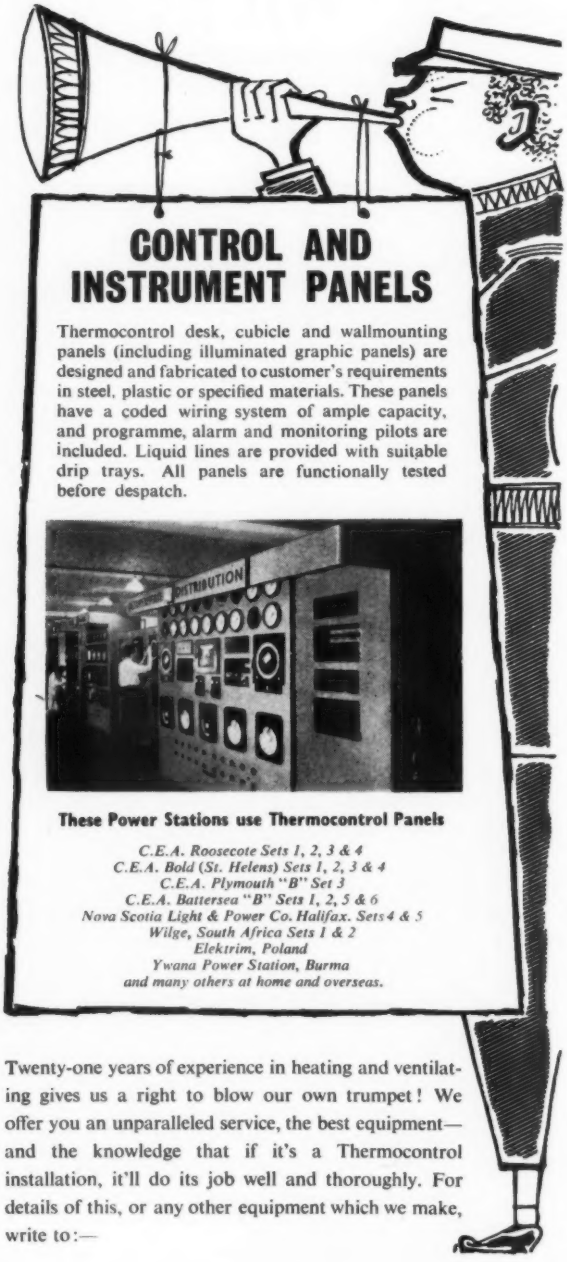

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Thermocontrol desk, cubicle and wallmounting panels (including illuminated graphic panels) are designed and fabricated to customer's requirements in steel, plastic or specified materials. These panels have a coded wiring system of ample capacity, and programme, alarm and monitoring pilots are included. Liquid lines are provided with suitable drip trays. All panels are functionally tested before despatch.

These Power Stations use Thermocontrol Panels

C.E.A. Roosecote Sets 1, 2, 3 & 4
C.E.A. Bold (St. Helens) Sets 1, 2, 3 & 4
C.E.A. Plymouth "B" Set 3
C.E.A. Battersea "B" Sets 1, 2, 5 & 6
Nova Scotia Light & Power Co. Halifax. Sets 4 & 5
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and many others at home and overseas.

Twenty-one years of experience in heating and ventilating gives us a right to blow our own trumpet! We offer you an unparalleled service, the best equipment—and the knowledge that if it's a Thermocontrol installation, it'll do its job well and thoroughly. For details of this, or any other equipment which we make, write to:—

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Thermocontrol manufacture a complete range of controls for air conditioning, refrigeration, automatic temperature and humidity adjustment in process controls for automation.

safeguarding workers

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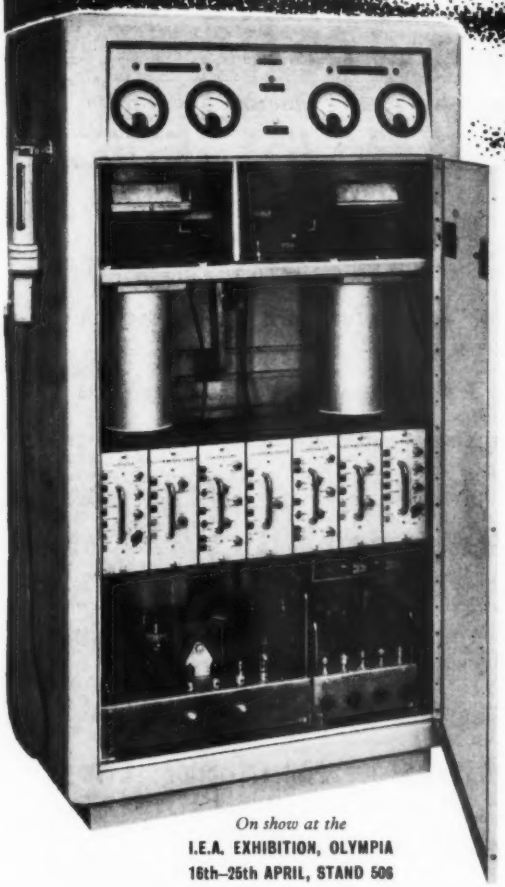

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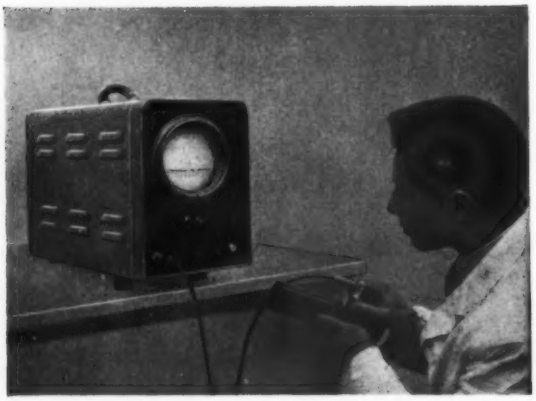

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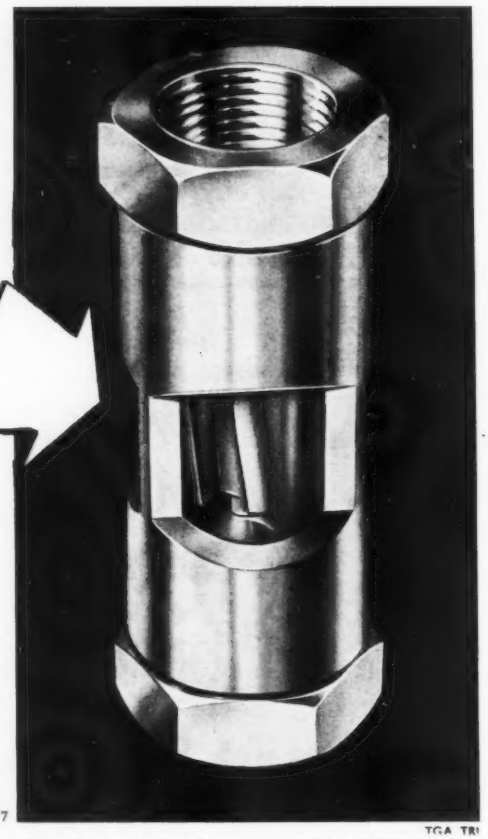

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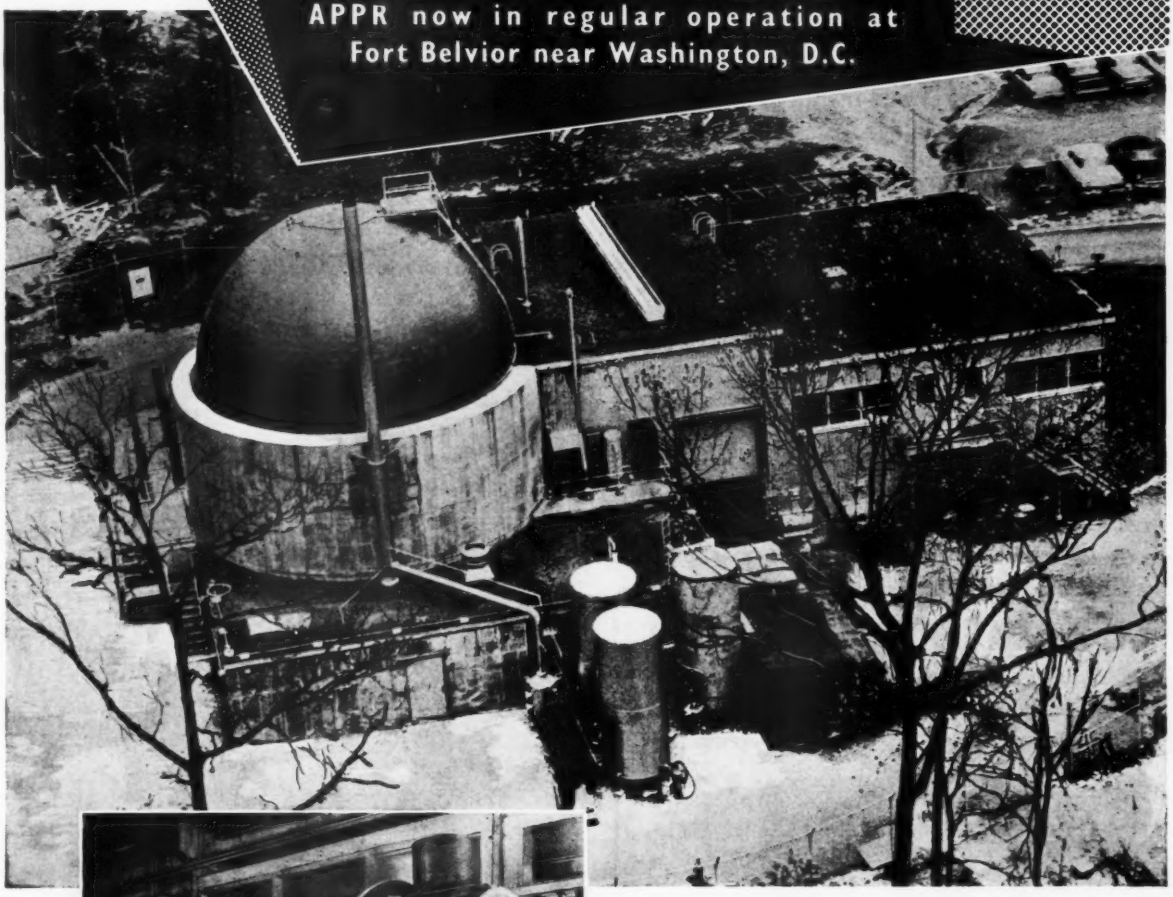

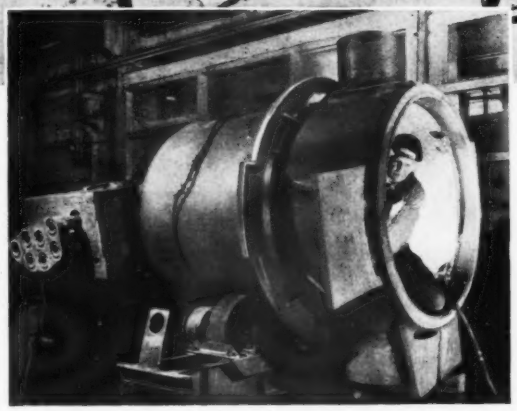

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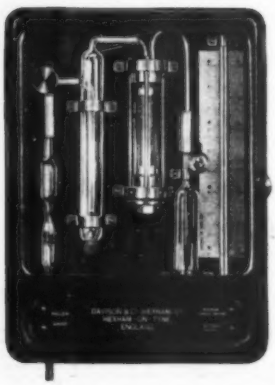

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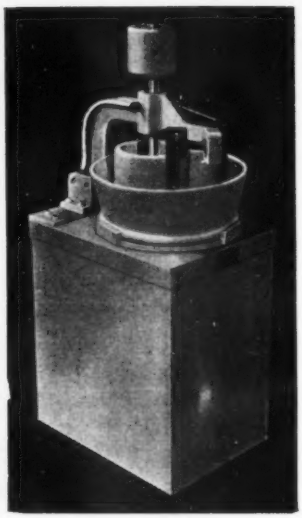

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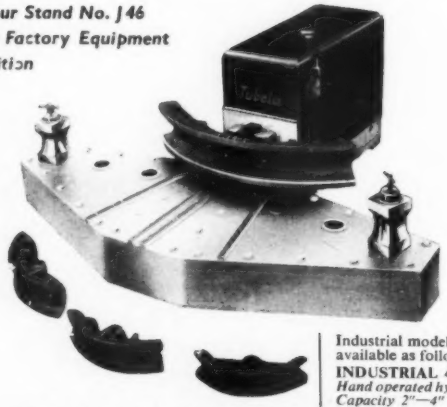

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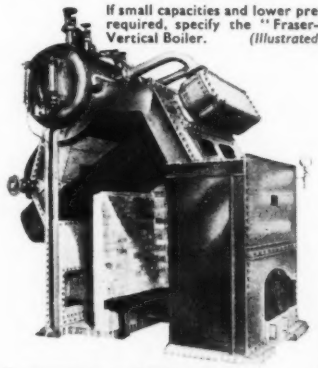

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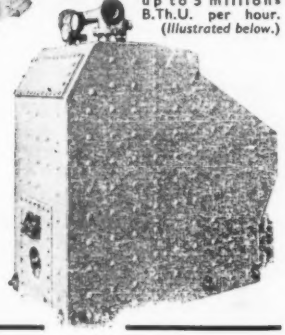

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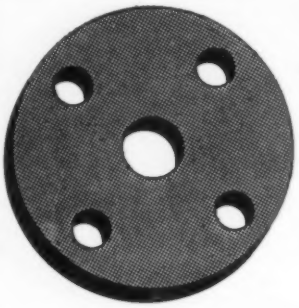

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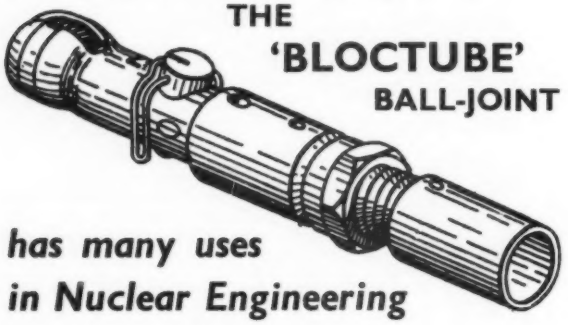

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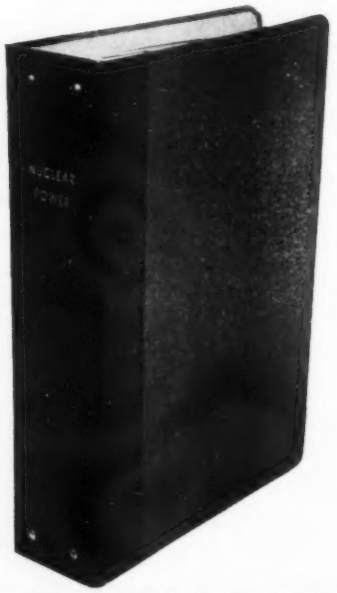

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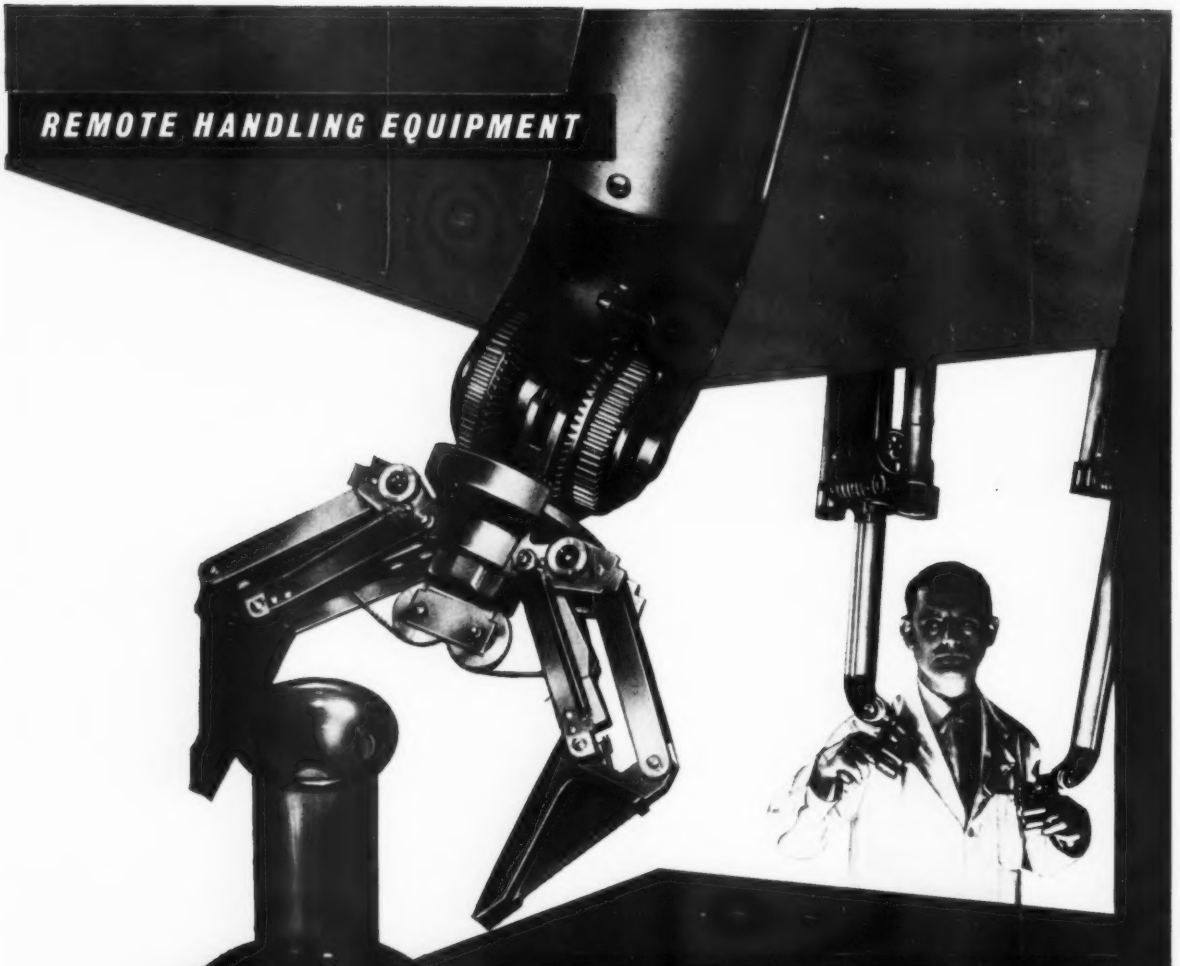

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